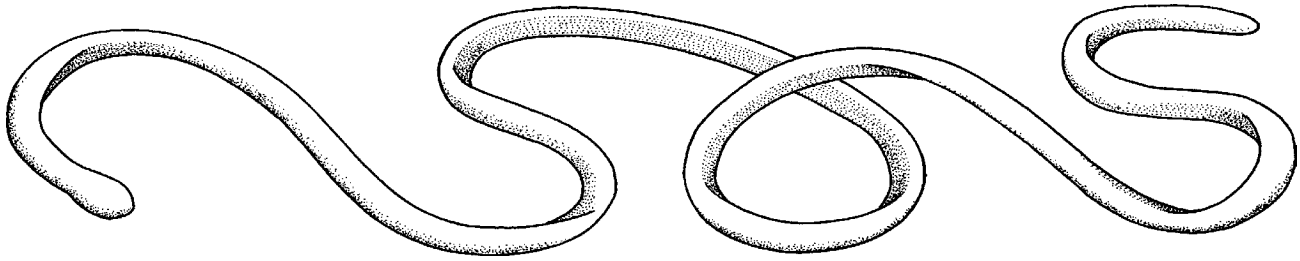


3 - Estuary Alive - Ecology

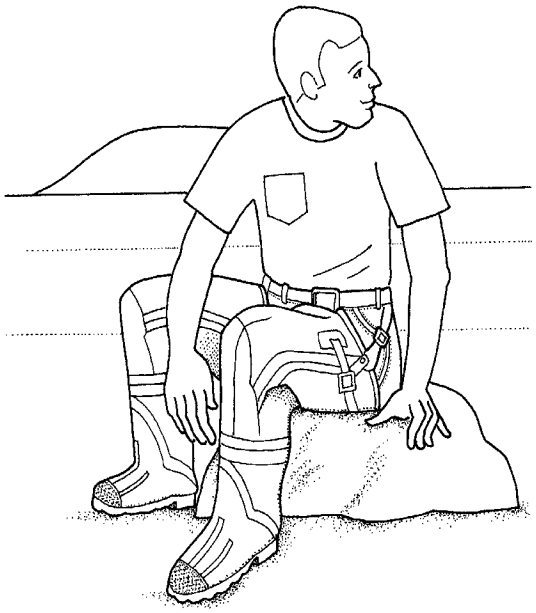
What you are about to read was told to a high school science teacher by one of her less than academic students. For the entire first semester of biology this student, although pleasant, was not what you'd call a lean, academic machine. Social temptations usually conquered school responsibilities. So, when this student earned a 100% on the final exam, frankly, it was somewhat suspicious. The story is retold here as an example of the mysteries being discovered in estuarine ecology.

It was a dark, clear night with bright stars and a slight shimmering of the Aurora Borealis as I headed to my home near Bay View. In spite of all this beauty I just couldn't keep my mind off of the spectacular sight I had witnessed earlier in the evening on the ferry ride to Anacortes. It must have been a meteor. Maybe it looked so close because of the northern lights in the background. But I'd seen meteors and this just wasn't the same. The movement of the object was too slow and controlled. And all other meteors seem to disappear harmlessly in the night sky while this seemed to fall right out of the sky!

As I turned north toward Padilla Bay I sank into the routine of driving that familiar road. Far away thoughts drifted through my head. Maybe I should have studied for tomorrow's biology exam instead of playing all weekend on the island. Not far from home, I glanced out over the bay for one last look at the shimmering waves of light over Hat Island when, to my amazement, I saw a glowing sphere far out on the mud flat. The music from "Twilight Zone" was twinkling in my head as I turned off the road and pulled into the parking lot near the beach. I rubbed my tired eyes, fully expecting the object to be gone when I reopened them, but it was still there. A bluish, white light pulsed from the object and reflected off the shiny surface of the mud flat.

My first inclination was to drive home and call 911. But after thinking a minute, it occurred to me that if I were the first to make contact with alien beings (and what else could the glowing sphere possibly contain?) I might get some extra credit points from my biology teacher which might help make up for the lost study day. I opened the trunk, pulled on my hip boots, and started sloshing my way toward the space craft.

As I cautiously approached, a door opened. I expected to see a little green man emerge with either one or three eyes (certainly not two) that would talk in a squeaky voice and say something mundane like,



"Greetings, earthling," or "take me to your leader." But imagine my surprise when a pale, snake-like, writhing, mucous covered *proboscis* thrashed wildly out of the opening. I fell backward in horror and disgust. My hands became stuck in the mud in a reflex move to break my fall. The slimy proboscis whipped back in my direction and, as I sat there defenseless, wrapped around my neck and across my face. Pulling my right hand free from the mud and then my left, I grabbed the proboscis and peeled it off like a piece of masking tape. I started to slide back in retreat, deciding that I was wrong not to have called 911, when I heard a squeaky, nasal voice, "Greetings, earthling."

I breathed a sigh of relief in the thought that at least something about this experience was predictable and replied, "Greetings yourself. Why did you attack me?"

"Well, it's just my way; these are my sensory organs. Don't take it personally," said the creature. "I have a lot of questions to ask and very little time because when the tide comes in, we're sunk." The creature laughed uncontrollably at his own pun until I interrupted.

"Who are you, where are you from and why are you here?" I asked.

"All fair questions," the creature replied. "I am a Nemartian from the planet Stasis. I have been sent here to interview an average earthling and learn of the environment here. I was specifically directed not to talk to a 'leader' as that information would probably be unreliable. You're not a leader are you?"

"No," I replied, "but . . ." and before I could go on, the Nemartian started questioning me.

"My planet is one huge mud flat," the Nemartian said. "As I circled for my landing, I noticed that it is not so here. There seem to be several strange habitats surrounding this familiar mud flat. Can you explain how you organize all this complexity?"

Suddenly I was faced with the prospect of having to explain my environment to an alien! This Nemartian didn't have a clue and I, of all people, had become the expert. As I glanced around the bay, things that I had been only half listening to in school started to crawl out from their hiding places in the nooks and crannies of my brain and stand out in clear detail. I began to think this might even be fun!

Classification

"You're right," I said to the Nemartian. "This is a complex place and it is difficult to keep track of things sometimes. But we humans have devised systems of classification to simplify our perceptions of the earth. What you noticed, as you circled, was the Padilla Bay *estuary*. It's an important *ecosystem* here." I can't explain it, but I somehow

sensed a blank stare from the proboscis. I concluded that I would have to define my terms.

"An ecosystem," I continued, "according to my biology book, is a distinct, self-supporting unit of interacting organisms and their environment. The ecosystem you landed in is an estuary, a place where fresh water flows into the sea."

"I think I understand," said the Nemartian. "This ecosystem I observed is somehow walled off from the others, making it 'distinct and self-supporting.' What is the nature of these walls?" I started to realize this wasn't going to be as easy as I had originally thought. I guess it wasn't so much the Nemartian's fault, though, as it was the fault of our classification. We use terms to try to define things for our convenience but, come to think of it, the environment doesn't really make these distinctions.

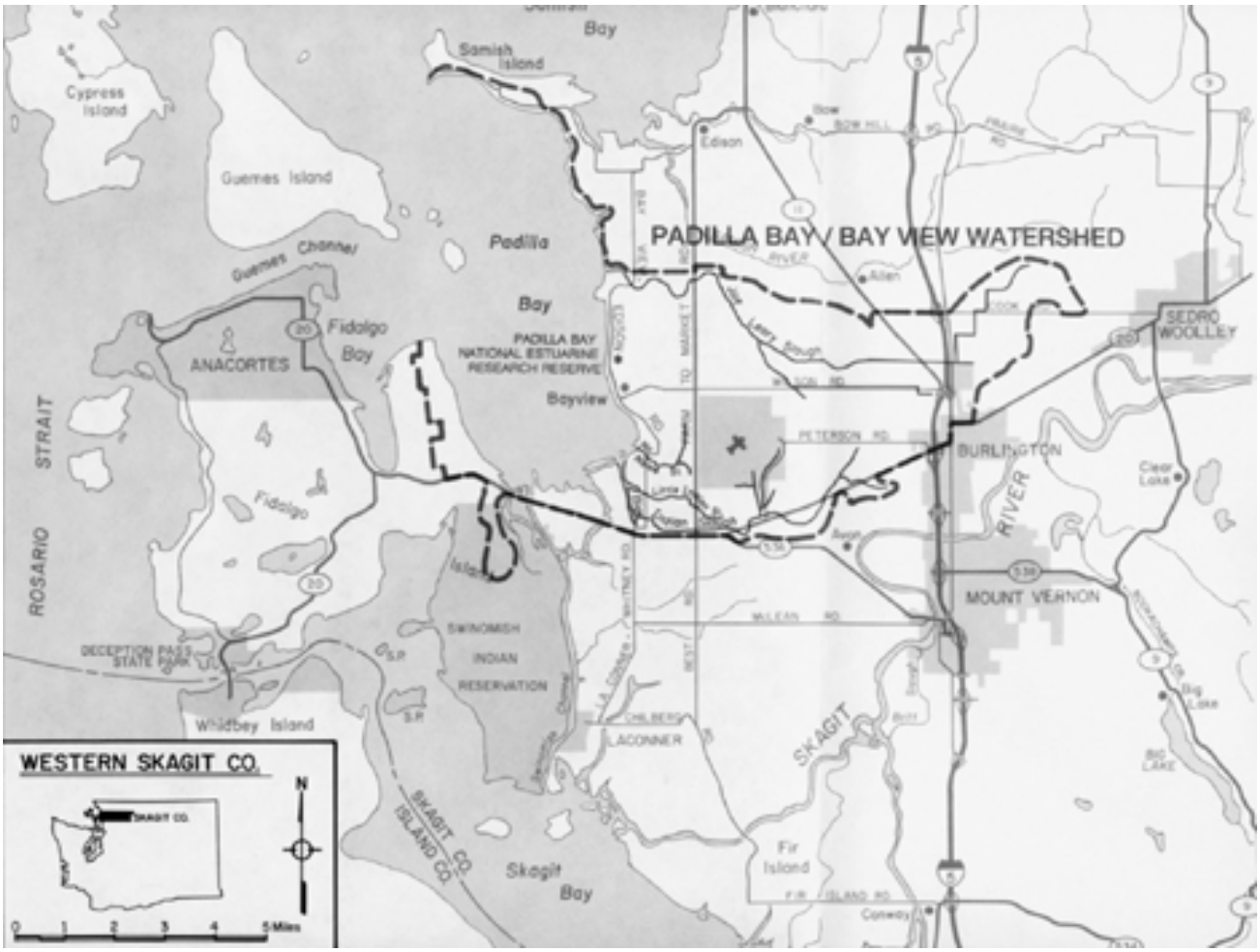
"No," I explained, "you've got the wrong idea. There are no walls. In fact, all the ecosystems on earth are interconnected." I thought if I explained the water cycle and *watershed*, he might get the picture. "Right now the seat of my jeans is pretty well saturated, but that water hasn't always been here. It may once have been on that farmer's field over there, or on my high school parking lot, or even in the Pharaoh's wine!"

The Nemartian didn't seem to get it, so I elaborated. "Picture a drop of ocean water. It evaporates from the surface of the ocean, enters the atmosphere as a gas, condenses with other water molecules to form a cloud, travels landward with the wind, condenses further until it falls to earth in heavy droplets, obeys the forces of gravity and moves downhill until it drains into a tiny rivulet and, picking up speed, drains into a rushing creek that drains into a torrential stream that drains into the powerful, surging Skagit River that flows ever downward toward the sea. Eventually, the water ends up in the Skagit's estuary. Some of that water may end up here in Padilla Bay.

"A *watershed* is all the land area that drains into a river or body of water. One watershed can include many ecosystems. Padilla Bay's watershed is pretty small, in fact, you can see most of it from here. All the rain that falls on those farms over there and that forest over there drains right into Padilla Bay. Other watersheds, like the Skagit's, are enormous and may include glaciers, timberland, and cities. The point is, this water has been a lot of places and carried a lot of things, some good, some not so good, to this estuary."

"Like what?" asked the Nemartian, looking somewhat drained itself at this point. (I use "it" because it was virtually impossible to determine the sex, if any, of this creature. And . . . it really didn't seem to make any difference.)

"The river picks up and carries *sediments* when moving fast but when it slows down in the flats, the sediments fall out and become trapped in the estuary. This vegetation you see covering the mud here slows the water even more and helps hold the sediments here. The river carries dead plants and animals in various stages of decay and deposits them here. We call that *detritus*. Those things are okay but other things come down the river and end up here. Feces from dairy cows, human sewage, chemicals from industry, oil that is washed off our roads, and fertilizer from our lawns all eventually end up here. So, you see, there are no walls to separate ecosystems. Whatever happens in one will eventually affect others."



And so began a long series of questions about an environment that I knew well. After all, I had lived near Padilla Bay all my life. I had observed many things on my own while exploring the rivers, beaches, mud flats. Also, I had learned things just sitting in class, listening to teachers explain the underlying concepts and principles of science, history and the humanities. What was different, though, was that somehow, standing out on the mudflat at night, in the presence of the Nemartian brought about a synthesis of all this knowledge. I could now see the connections that linked and intertwined all the observations, ideas and information that had ever entered my brain.

The Abiotic Estuary

"If there are no walls then what **does** make this estuary an ecosystem? Why is it any different from the hills and mountains and ocean around it?"

This was a tricky one and I thought hard. "I guess each system is uniquely shaped by the abiotic elements -- in this estuary it's the water, the mud, and the climate that determines what will live here. An estuary is not an easy place for an organism to live because the conditions change so much. The water here is constantly changing due to the flow and ebb of two daily tides (at this point the Nemartian lowered its proboscis

toward my watch). Tides, plus the irregular influx of fresh water, results in changes in salinity, temperature, dissolved oxygen, and pH."

"This is of particular interest to me," replied the Nemartian. "On my planet Stasis, there are no such changes. Everything is always the same. Tell me the details of these changes."

Tides

"Tides are the result of two physical forces: 1) the **gravitational** forces of the sun, the moon and the earth and, 2) the **centrifugal** force caused by the rotating earth and moon system. These forces cause the water in the ocean basins to be pulled into bulges.

Both the sun and moon are exerting gravitational force on the earth. This force pulls the water in the oceans into a bulge on the sides of the earth closest to the sun and moon. Because the moon is so much closer, its tide raising force is more than twice that of the sun.

"While the moon is pulling on one side of the earth, centrifugal force is pulling on the side opposite the moon. If there were no moon, the rotation of the earth would exert centrifugal force equally, in all directions, much as a dancer's skirt twirls when she turns.

But because the earth and moon are rotating together, the center of rotation is not at the center of the earth, but is closer to the moon. This causes a greater centrifugal force on the side of the earth away from the moon. Picture a mother and child holding hands and spinning in a dance. The mother's skirt will lift higher on the side away from the child." rshed

"What is a dancer and what is a skirt?" asked the confused Nemartian.

The earth-moon system rotates like a mother and child dancing.

"Never mind. It's not that important. What is important is that the gravitational pull of the moon is making the water bulge on one side of the earth (causing high tide) while centrifigal force is making a bulge on the other side (another high tide). In between the bulges there is less water, and therefore, low tide.

"Tides would be pretty simple and predictable if that was the whole story, but there's a lot more we don't have time to get into.

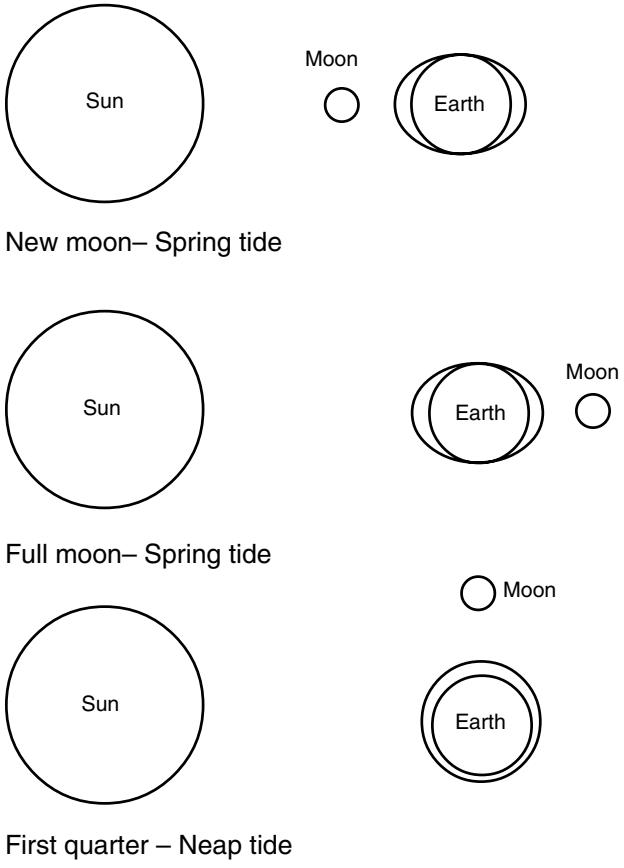
The sun is also exerting gravitational force, and because the earth-moon system is not only rotating, but also revolving around the sun, there is a second centrifugal force. Add to that the fact that these bulges or tidal waves keep bumping into land and bouncing back, and you have a very complex picture.

"You're lucky you came here today. There is a new moon, and that means that the tide is especially low right now. Because the sun and moon are both on the same side

of the earth, they pull together, causing an extra large bulge. In two weeks, the moon will be on the side of the earth opposite the sun, and forces will again be lined up, meaning higher (and lower) tides. These extreme tides are called *spring tides*. On the weeks between, the forces of sun and moon will be pulling in different directions, and will tend to cancel each other out. These are *neap tides*, and aren't nearly as high or low.

"Life between the tides is not easy. Organisms have lots of adaptations to deal with the changing water level. Some plants can completely dry out at low tide on a sunny day and survive. Others, like eelgrass can't dry out, and only grow in areas where they stay wet; areas like the very flat mud here in Padilla Bay.

"Some of the larger animals like fish swim out with the tide. Others have various strategies for staying wet. Clams, barnacles, oysters, and mussels can close their shells tightly to keep water in. Snails and limpets clamp tightly to rock. Some animals burrow into the mud and sand. Some hide under rocks. Then there are those animals just waiting for low tide to munch out. If you'd been here earlier this evening, you would have seen hundreds of gulls and herons following the edge of the water as it receded."



Tides are affected by the positions of the earth, moon, and sun.

Salinity

"Now, as you might predict, when the tide is high, the salt water is driven far up into the estuary. This occurs twice in a 24-hour period here in the Northwest. Low tides, by contrast, allow fresh water to dominate the estuary. Other marine environments are not subject to such exaggerated change.

"So salinity in the estuary is the result of a constant battle between the freshwater from the land trying to dilute the salt water of the sea. High tide gives the advantage to the sea while low tide provides an advantage to the fresh water. But the fresh water recruits help during flood season. With increased fresh water flow, the battle lines (or salinity gradients) are moved downstream. Therefore, at different seasons of the year, different salinities can be expected in different areas of the estuary.

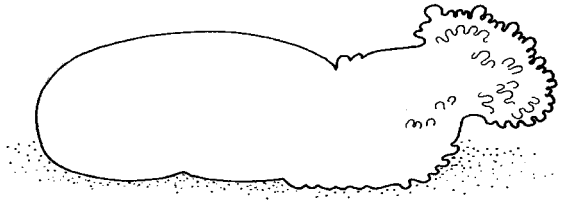
"Salt water is denser than fresh water, you know, so it tends to sink to the bottom. There is often a distinct layer of fresh water

floating above the salt water. We call that *stratification*. Wind, waves, and tides can stir up the layers, so estuary animals and plants need to be prepared for quick changes in salinity."

"How could any living thing possibly survive in such an unpredictable place as this?" the Nemartian asked.

"Animals have different strategies for dealing with changing salinities. *Osmosis* is a fancy word for what happens in many animals when the salt content or concentration inside their cells is different from the concentration outside (in the water). The water simply passes through the cell membrane until the concentration is equalized. For example, if a jellyfish or sea cucumber finds itself in water that's saltier than its cell content, water passes out of its cells until its cell fluids become as salty as the water. If the surroundings become fresher, then water enters its cells until they are fresher, too. Of course, too much change could be fatal, and most organisms have a range of salinity in which they can survive."

Sea cucumber in very salty water



Sea cucumber in fresh water

Osmosis at work

"An animal like a clam or snail closes up when the salinity moves beyond its tolerated range. Other animals, like salmon, have an active mechanism that maintains a constant internal fluid medium. When a salmon is in freshwater, it experiences a water **gain** by osmosis. It compensates by not drinking and excreting lots of diluted urine. In salt water, the salmon experiences water **loss** by osmosis, so it drinks lots of sea water, produces a little bit of very salty urine, and secretes excess salt through cells in its gills. I guess you can see that life isn't simple where fresh and salt water mix.

"In the *sediment*, things are different. As you know, the mud we sit on is permeated with water." (I was especially aware of this since my rear end was soaked!) "The water is held in the spaces or *interstices* between the particles of sediment. This interstitial water obviously originates from the overlying water, but it moves slowly due to the density of the mud. Therefore, the salinity of interstitial water is not subject to the changes occurring in the water above, and remains relatively constant. Organisms that live burrowed in the mud are buffered from drastic changes in salinity."

"My kind of people," replied the Nemartian with a homesick expression. "Tell me more about this mud or sediment, as you called it."

Sedimentation

"Most estuaries are dominated by muddy sediments such as these. They are deposited from both the sea and land.

"Strong ocean currents can scour the sea floor. When the currents slow down in the sheltered estuary, the reduced motion lets the mud settle out. I remember reading

estuary of the River Thames had been *dredged* and the material dumped into the sea. Ocean currents returned the dredged materials to the same estuary a short time later!

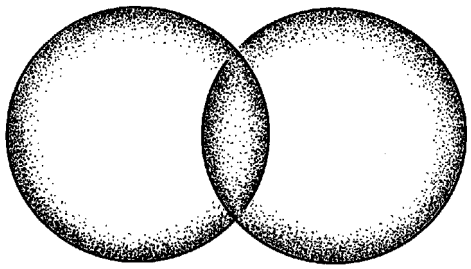
"Rivers and streams carry silt in suspension. When these suspended particles mix with the various charged particles (ions) present in the sea water at the estuary, they flocculate or clump together. They become larger and heavier and thus settle to the bottom.

"It is interesting to see how these sediments are deposited in the estuary. Stronger currents can keep larger particles in suspension. As the current slows, the largest particles begin dropping out. Where there are strong currents, like along the channels that flow through the mud flat or near the upper reaches of fresh water drainage, the sediments are coarse (sand or gravel). In areas of the estuary where currents are slower, the sediments are dominated by fine silt, or mud.

"Many of the particles that settle out in this way are bits of dead plants and animals. A good term for this material is *detritus*. Imagine all of the dead organisms, in various stages of decay, that are carried here from both the sea and the river, then add them to all of the dead organisms in the estuary itself. Why this is a virtual detritus grave yard. This material is very important to organisms that live in the estuary since it is such a good source of energy."

"So they have everything they need right in the mud!" the Nemartian concluded.

"Well, they have plenty of food but they still need something to breathe."



Oxygen

"As you may know, oxygen will dissolve in water just like a spoonful of sugar in iced tea." The Nemartian looked puzzled at this point but I pretended not to notice and went on. "So, the regular influx of fresh and salt water into the estuary, coupled with the shallowness and surface turbulence, usually provides plenty of oxygen in the water. As the temperature and salinity change, the ability for water to hold oxygen changes. That means the oxygen is not constant in any one place at any one time. But in the substrate, it is a totally different matter. As I mentioned before, the interchange between interstitial water and the water above is slow. Although the mud is rich in nutrients (the result of detritus accumulation), the supply of oxygen (necessary for *aerobic* organisms) is a limited resource. The bacteria in the sediments use up a lot of the oxygen in the interstitial water. Estuarine sediments are anoxic (without oxygen) below the first few centimeters as you can see by the color change." deposited from both the sea and land.

I took out my pocket knife, cut a cross section from the mud and held it up to the light of the space craft. The Nemartian noted the difference between the light brown mud at the surface and the black-as-tar stuff down below. "There is no oxygen in this black layer. The *anaerobic* bacteria which live here

produce hydrogen sulfide as a by-product of respiration, accounting for the strong sulfur smell." I held the cross section of mud out so the Nemartian could lower its proboscis and take a whiff. "So the mud, while being rich in food, has no oxygen making it hard for organisms to survive. Burrowing animals have adapted means to beat the system. Many of them excavate tunnels through which the oxygen rich water can flow. This not only benefits the burrower but also the microorganisms living nearby." Just then the Nemartian interrupted.

"My sensors tell me the temperature is falling. Is there someplace we can go to get out of the cold?"

"Sorry, not around here."

Temperature

"The temperature in the ocean is pretty constant. Marine organisms that never venture into the estuary can count on temperatures in a fairly narrow range. But, estuaries experience a wide range of temperatures.

"Fresh water temperatures change with the seasons. Rivers in temperate regions, such as this, are colder than the ocean in winter and warmer than the ocean in summer. As a result, estuarine waters have the same seasonal variations. There are also daily variations because of the changing tides. Because an estuary is shallow, the water heats and cools easily.

"Temperature variation poses one more survival problem for estuary organisms. A very hard winter, for example, can cause catastrophic mortality."

"So why on Stasis would anyone choose to live in this unreliable place?" the Nemartian asked in a baffled voice. I started to sense some frustration. I think he thought this would be simpler to decipher.

"I don't know," I replied. "Most species have colonized this habitat from the temperature-stable sea. I guess they come for the detritus. Or maybe they're trying to escape some particularly bothersome predators. Whatever the reason, plants and animals seem to love it here."

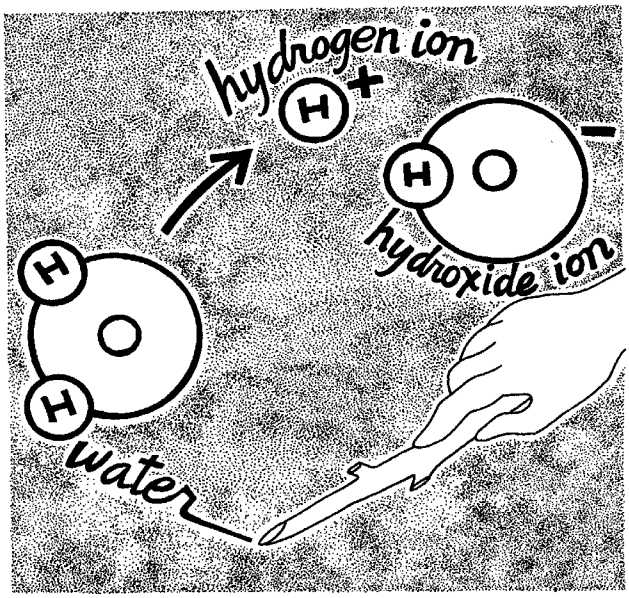
"I noticed you haven't asked about pH," I said. I had been enjoying this trip through my memory bank so much that I wanted to search all the dark corners. The concept of pH had always been a little confusing to me but now that everything seemed so clear, I thought I'd like to give it a whirl.

"O.K., tell me about pH," the Nemartian said, sounding a little perplexed but not wanting to admit to it.

pH

"Well, pH, as I'm sure you know being a space traveler and all, is the scale used to describe the amount of hydrogen ions present in a water solution. We think of the water molecule as H_2O; two hydrogen atoms attached to one oxygen atom. This concept of a permanent structure makes it easy to think about. But in reality, the molecule comes apart a lot, losing one of the hydrogens. The result is one hydrogen yanked away from the oxygen, leaving its electron behind with the remaining oxygen-hydrogen complex. The free hydrogen now has a positive charge (since it left its negatively charged electron behind) and is called a hydrogen ion. The oxygen-hydrogen complex has a negative charge (since it acquired the extra electron) and is called a hydroxide ion."

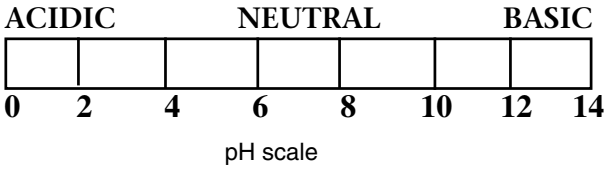
The Nemartian could no longer contain its confusion. "Say what!?!" I drew the following picture in the mud to help clear things up:



That seemed to help, so I went on. "Some things, when mixed with water, cause lots of hydrogen ions to be floating around free in solution. This is because they attach easily to the oxygen-hydrogen complex, leaving no place for the free hydrogens to attach. Consequently, we say the solution has a high hydrogen ion concentration and is **acidic**. It would be assigned a value of less than 7 on the pH scale. Other things combine readily to the free hydrogen ions and actually reduce the hydrogen ion concentration. This results in a **basic** solution which would have a value greater than 7 on the pH scale. A neutral solution (pH 7 on the scale) has equal amounts of hydrogen ion and hydroxide ion."

"The level of pH, like all the abiotic factors we have been discussing, is significant to organisms living here. Changes in pH can affect the solubility of minerals required by the eelgrass, for example. Enzymes, which mediate all biochemical reactions of living things, require specific ranges of pH to operate efficiently.

"The open ocean contains strong basic ions such as sodium, potassium and calcium. These are examples of particles that attach readily to the free hydrogen ions, leaving a basic solution. This is moderated by the presence of carbon dioxide which acts as a *buffer* to keep sea water within a fairly narrow range. It does this by absorbing hydrogen ions in the water when they are in excess and producing more when they are in short supply. The resulting ocean water is still on the basic side, with a pH range of between 7.5 and 8.4.



pH scale

Approximate pH's

1.0 - stomach acid	6.3 - milk
2.0 - lemon juice	7.0 - distilled water
2.5 - vinegar	7.5 - human blood
<3.5-all fish die->9.5	11 - ammonia
4.0 - oranges	12 - bleach
5.6 - normal rain	13 - lye

"Fresh water entering the estuary typically has a lower pH than the open ocean. The effect on pH in the estuary is the same old story told for temperature and salinity. The mixing of fresh and salt water produces varying levels of pH that organisms have adapted to."

"This is all so incomprehensible," uttered the Nemartian, sounding weary. "Things are so much simpler on Stasis. Is this constant fluctuation typical of your entire planet?"

"Well, maybe not quite so extreme," I replied. "The ocean, about 100 miles behind you, is fairly stable and that's where life got its start. But when things began getting crowded and competition became the mode of existence, organisms started looking for greener pastures. Some of them came to the estuary. This movement away from a previous niche is called *adaptive radiation*.

"The estuary is an example of an ecosystem where an organism can find plenty of food if it can meet the tough demands imposed by the constantly changing conditions. And, the harsh conditions may even prove beneficial if they discourage predators. But the estuary, as a habitat, is not for everybody. Relatively few species have been able to successfully make the transition. While there is lots of life here, the diversity of life is very low. In other words, the number of organisms is high but the number of species is low. This is due not only to the unusual conditions but also to the fact that temperate estuaries are relatively new places. They were formed just after the last glaciation, probably less than 10,000 years ago. So you really have to hand it to the plants and animals living here. They have adapted quickly to harsh environmental conditions in a variety of ways and contribute to a very unique and fascinating ecosystem."

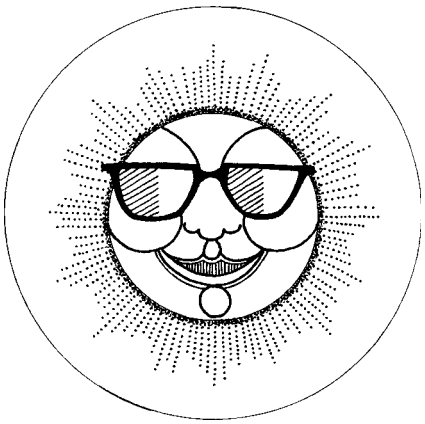
I was anxious at this point to move on and talk more about the organisms that inhabit the estuary. "I'll tell you what," I suggested, "why don't we liven this discussion up with some talk about the *biotic* elements of the estuarine ecosystem?" The Nemartian nodded in agreement.

The Biotic Estuary

For the first time I seemed to be at a loss for words. I knew what I wanted to tell the Nemartian but I just couldn't decide where to start. "Where do I begin?" I thought out loud.

"Well, . . ." the Nemartian suggested, "on my planet, we always start at the beginning!"

"Well, . . ." I countered, "on this planet, things are cyclic. One thing leads to another and then another until you're right back where you started and things don't ever start or stop anywhere." Again the Nemartian looked baffled and I felt sorry for it. All things considered, this must be a trying time for an alien, light years away from home, trying to decipher an ecosystem before the tide comes in. I took a deep breath and picked a starting place at random.



Productivity

"Let's talk about energy. An ecosystem involves a flow of energy that starts with the sun. All organisms need the energy flowing in the system to grow and reproduce, but they get the energy in different ways. We've got autotrophs, heterotrophs, chemotrophs . . ."

The Nemartian's quizzical expression indicated that there was some confusion as

to where this discussion was leading. I was learning to read its proboscis like a book.

"*Autotrophs* use the sun's energy, *heterotrophs* use energy from the autotrophs, while the *chemotrophs* use energy from inorganic chemicals. The only chemotrophs I know are certain bacteria that *oxidize* simple inorganic compounds like ammonia, nitrite, and sulfide." The Nemartian looked as if it was beginning to see the point.

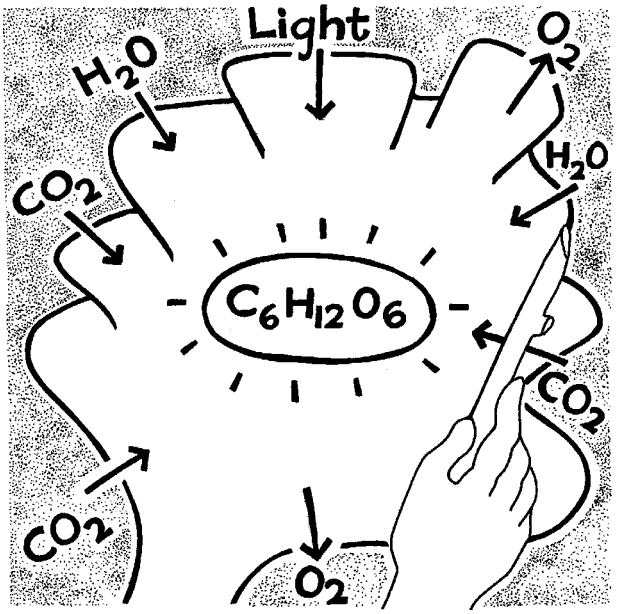
"Autotrophs, or 'producers,' harvest energy from the sun to convert inorganic carbon dioxide and water into the organic compound sugar. The process is known as photosynthesis."

The Nemartian looked amazed. "Do you mean to tell me that some organisms can make molecules with light energy? Are you pulling my appendage?"

"No," I assured him. "Photosynthesis requires a particular pigment molecule called chlorophyll. It has the unique property of capturing photons of sunlight, kind of like a solar collector, and using that energy to set in motion a series of biochemical reactions that result in the production of glucose. The energy stored in the glucose is used by the autotroph or passed on to the heterotrophs if it gets eaten."

"That's incredible!" the Nemartian squealed.

"Yes, with just water, carbon dioxide and the energy provided from the sun, these photosynthesizers provide the starting material required to sustain life on this mud flat and everywhere else on the planet." It was time for another mud drawing:



A photosynthesizing blade of green algae

The Nemartian studied the drawing. "Where did the oxygen come from?" he asked.

"The oxygen is a by-product of photosynthesis. Not only are the producers responsible for creating sugar, they also contribute all of the atmospheric oxygen. Without the producers, you and I would have no oxygen to breathe."

"These producers must be the most revered and protected organisms on earth," commented the Nemartian. "Are these the leaders I was warned about?"

"Well, not exactly," I answered.

"Then introduce me to the producers here in Padilla Bay," said the Nemartian.

Producers in Padilla Bay

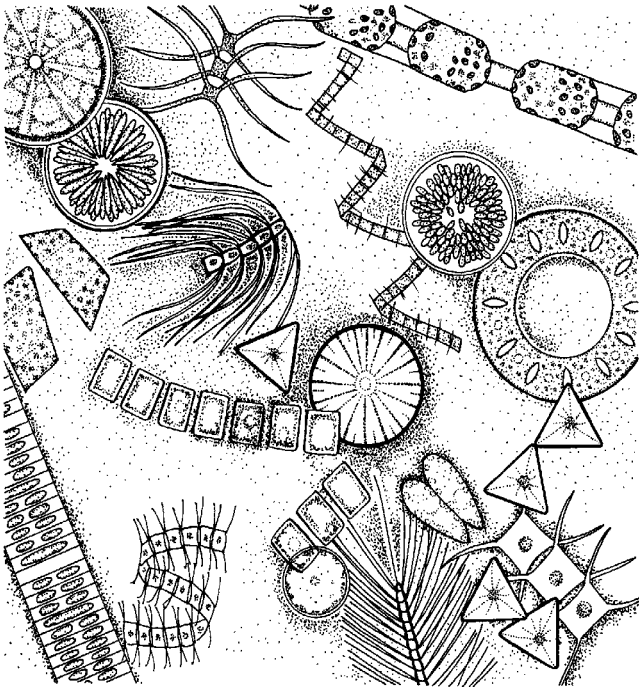
"Some of them are too small to see, but they're hard workers. Primary production (that's the photosynthetic production of sugar) here in Padilla Bay is really incredible. There is twice as much production here as in a farmer's best fields; three times as much as in that healthy forest up on the hill."

"Wait a minute", said the Nemartian. "You're telling me that this barren mud patch produces more sugar and more oxygen than those huge plants over there? Then where is all this growth and reproduction you were telling me about?"

"You can't always see it. Think of a corn field. It starts out in the spring as bare dirt. By the end of the summer 'the corn is as high as an elephant's eye!' That's a lot of growth. The mass of all the living things in the field, or *biomass*, has built up over the summer. But then in the fall, the farmer comes along, cuts it down, hauls it away, and sells it to consumers who live elsewhere. The ground looks bare again but in one year one acre of that field produced a lot of corn.

"Now in a forest you can see production accumulate. There is not as much produced each year but there is less export." In my mind's eye I saw a clear cut but decided not to confuse my new friend with all that. "In a healthy forest bits of dead leaves wash away with the rain and berries and seeds get carried away but the total biomass keeps increasing year after year.

"Here in the eelgrass meadows the productivity is greater than either of those other ecosystems. Even the bare mud surface is covered with microscopic producers called *phytoplankton*. Tiny *diatom*s and *dinoflagellates* photosynthesize so fast that organic products ooze out into the water. Sometimes I see an oily sheen on the water that looks like a gasoline spill, but it's actually just organic matter. Consumers like bacteria turn it into a foamy froth that looks like soap suds washing up on the beach."



Diatoms

My friend still wasn't satisfied. "Where does this incredible amount of production go?"

"The tide washes it away, salmon come in here and gobble up the little consumers, great blue herons and eagles come and carry away huge amounts of biomass. The export rate is so high that the biomass never builds up very much."

"I sure couldn't tell it's that productive just by looking at it," said the Nemartian.

"That's why for so many years people didn't realize estuaries were important. They

looked out and saw wastelands, not wetlands. They thought it would be better to turn them into farms, marinas, deep water ports, and industrial parks."

"Aren't there some producers out here that we can see?"

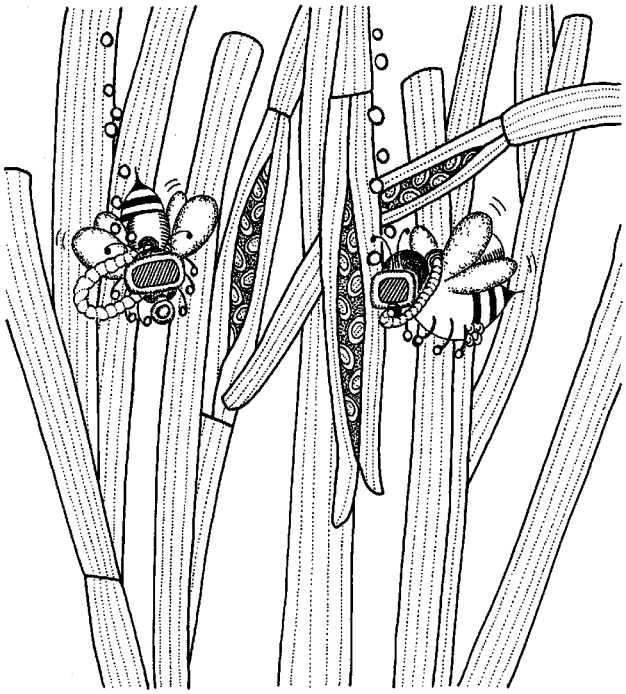
"Sure. Look at the green algae over there. And here are clumps of branching red algae. Look at this eelgrass. Eelgrass is a major producer in this estuary. The *indigenous* eelgrass that is growing out here where you have landed is the *Zostera marina*. Closer to shore is the smaller, non-native, *Zostera japonica*. *Zostera japonica* was accidentally introduced to the area when Japanese oysters were brought here in the 1800s. Padilla Bay has some of the most extensive beds of eelgrass anywhere on the western coast of North America!"

The Nemartian did not look impressed.

"Eelgrass is a flowering plant!" I said.
"Is that unusual?" it asked.

"Well," I continued, "most flowering plants grow on land or at least hold their flowers out of the water. Eelgrass is a rare example of a flowering plant that can tolerate high levels of salinity along with all the other hardships imposed by an estuarine environment. In a way, eelgrass is like a marine mammal. Both evolved on land and subsequently turned to the sea to make a living.

"Eelgrass, like other flowering plants, must bloom and be fertilized." The Nemartian continued its blank stare. "So how do you think it gets fertilized under the water?"



"Scuba bees!" it said with a big grin.

I tried not to react so as not to encourage more bad jokes. "Unlike land plants, which produce very small, roundish pollen grains, eelgrass pollen is stringy and mucous-like. When carried from the parent plant by currents, it will be more likely to wrap around another plant and attach to the stigma. In addition to sexual reproduction involving flowers, eelgrass also reproduces vegetatively from creeping underground stems called rhizomes, like many of its terrestrial relatives."

The Nemartian still looked bored so I tried harder to convince it of the importance of eelgrass.

"These eelgrass beds you see before you are not only important because of their marine adaptations. The roots they produce act as traps for sediments that stabilize and

build the substrate. Further, the long, ribbon-like leaves slow water currents so that additional particles settle. This stabilization is extremely durable; able to withstand storms as severe as hurricanes. In the 1930s, an unknown disease swept the North Atlantic coast wiping out much of the *Z. marina*. The effects included a dramatic erosion of beaches due to the loss of sediment, no longer held by the *Zostera*, as well as the disappearance of the animals associated with the beds.

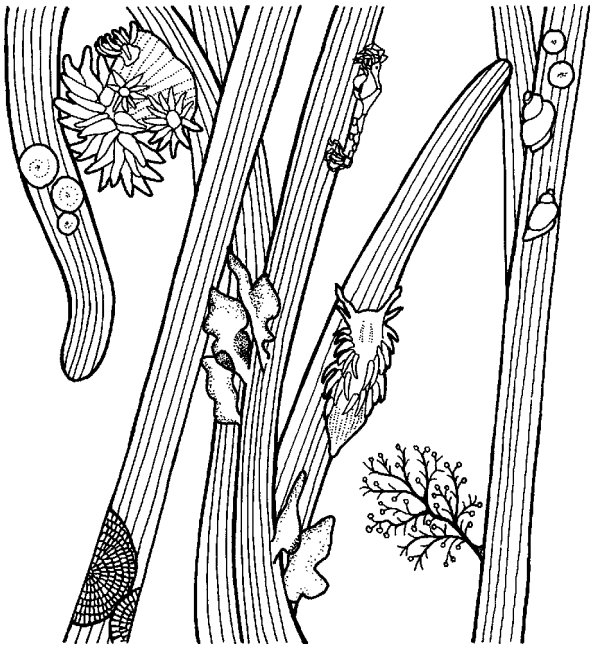
"The leaves also provide a protective canopy, shielding other organisms from the effects of strong sunlight. At low tide, the leaves cover the bottom substrate, protecting the inhabitants from drying out."

Now the Nemartian was beginning to move its proboscis in the direction of the extensive eelgrass bed near-by. I sensed a growing respect for the *Zostera marina*. This gave me new energy so I went on.

"See how it's covered with brown fuzz out near the ends of the blades? That's a whole community of small plants and animals that use the blades of the grass for habitat. The organisms growing on a plant are called *epiphytes*. The blades of eelgrass provide a rare solid *substrate* in this soft field of mud. Look closely and you'll see all sorts of inhabitants of this neighborhood -- tiny crustaceans, algae, sponges, bryozoans, worms... Is it any wonder so many hungry fish cruise these parts?"

"Let me see if I have this straight," said the Nemartian. "Eelgrass provides food, oxygen, sediment stabilization, and valuable habitat. So this must be the most revered organism in the estuary."

"Well, it should be I suppose. When the eelgrass is alive it does all those great things, but that's not all! When it dies, it accumulates with all the other dead plants and animals to become something even greater. Eelgrass is an important source of detritus in the estuary."



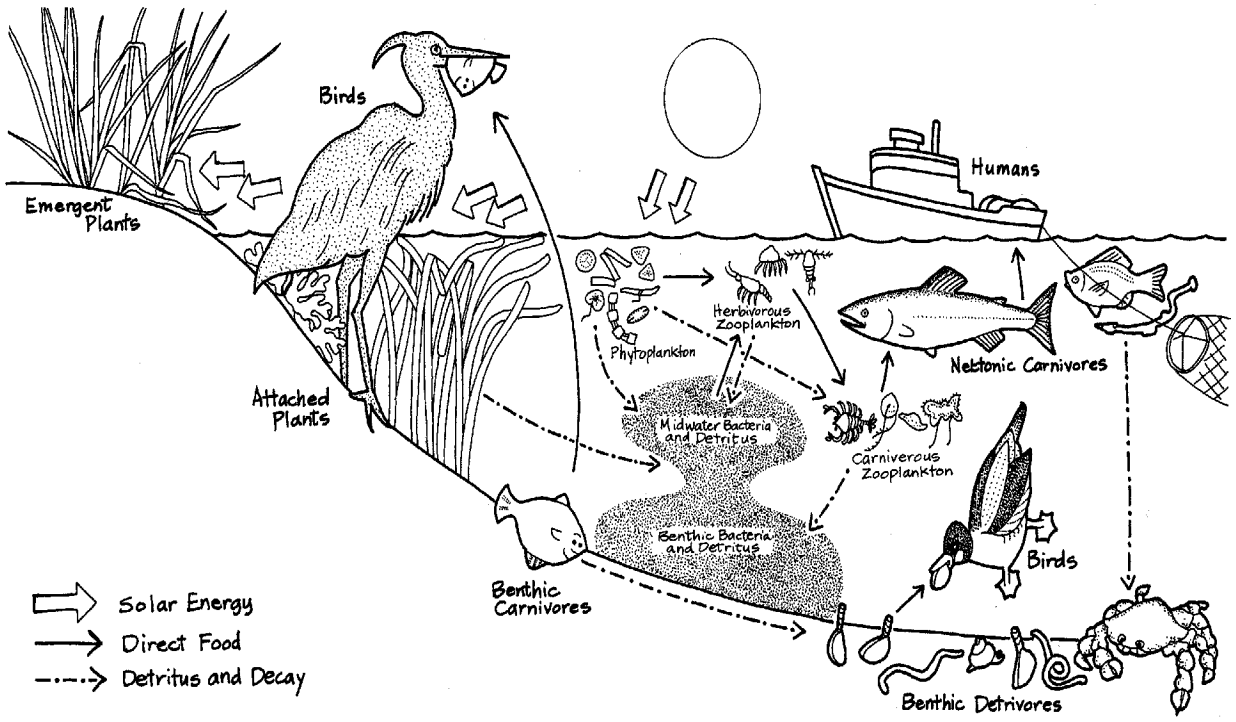
Eelgrass community

Food Webs and the Role of Detritus

"As in all ecosystems, some energy flows from the producers to the consumers (organisms that eat other organisms). These consumers living in the estuary depend on energy stored by producers such as eelgrass, algae, and phytoplankton. The major source of energy, however, is detritus."

"Excuse me," interrupted the Nemartian "This detritus, as you call it, is dead, right?"

I nodded. "Detritus is decaying organic material, but it is enriched with associated bacteria that are very much alive. Many ecologists believe that the consumers who



Estuary food web

eat detritus (*detritivores*) derive most of their energy by digesting the bacteria and other microorganisms that live on the particles of organic material.

"But that's not the only way energy is distributed in an estuary. There are primary consumers who eat the producers. There are secondary consumers who eat the primary consumers. *Omnivorous* filter feeders eat anything (detritus included) small enough to be sucked in with the water around them. An estuarine food web is very complex and I don't think anyone completely understands it."

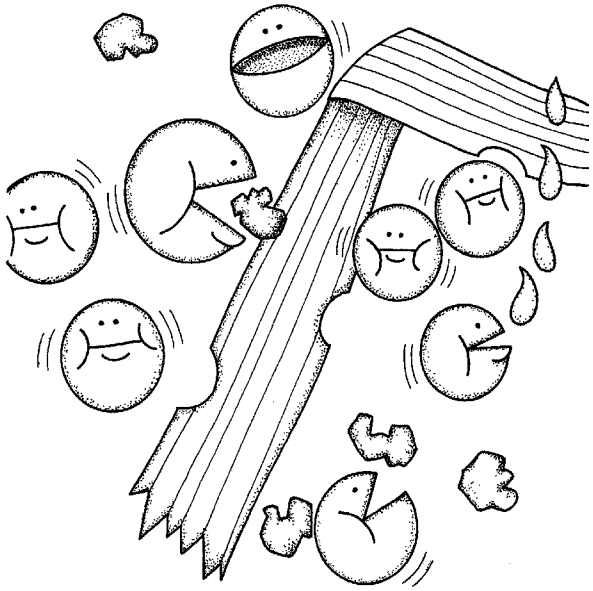
Estuarine Consumers

The Nemartian didn't look as confused as I had looked the first time I heard all this so I assumed I could continue.

"One group of consumers whose importance is often underemphasized, even in the text books, is the group I have already mentioned, the bacteria. Sure, I know they're small, but is that any reason to trivialize their impact on an ecosystem?" The Nemartian withdrew its proboscis a bit and I realized, in my enthusiasmto defend the underdog, I was coming on a little strong. I restrained myself and continued. "Both the water and the mud of estuaries are extremely rich in bacteria. It's a bacterium's dream down here due to the abundance of organic matter to decompose. The water that is beginning to lap around us contains hundreds of times more bacteria than open ocean water, and the upper layers of mud more than a thousand times more bacteria than that! Studies have measured 100-400 million bacteria per gram of estuary mud.

"And, contrary to what many believe, bacteria do much more good than harm. Certainly, the estuary as we know it would not exist without bacteria. The cycling of materials would be impossible without the decomposition of certain molecules by

bacteria. In other words, bacteria make the organic material available for all of the inhabitants of the estuary. Even the self-sufficient producers require the action of bacteria to obtain essential nutrients from the substrate.



Munching bacteria

"One role that I haven't mentioned is very remarkable. Bacteria can decompose just about anything. While a dead eelgrass leaf may be considered a tasty morsel to one bacterium, another might like a particle of raw sewage or even a potentially harmful toxic, washed down from an agricultural field. As a result, water passing through an estuary exits cleaner than it entered. A city in Texas has constructed a wastewater treatment facility in which sewage is piped into sixty-foot-high towers and bacteria like those here in the estuary are added. Within six to twelve hours, the organic substances are "eaten" by the bacteria and the purification process is complete. In our case, here at Padilla Bay, the estuary plays an important role in purifying water from the land. Now that so many estuaries have been destroyed, is it any wonder that the waters are polluted?

"However, it would be a tragic mistake to think that anything can be dumped into an estuary and it will be processed and purified. Estuaries, like all ecosystems, have their limits. If those limits are exceeded, then the entire balance is upset."

Estuarine Communities

The Nemartian's proboscis was now moving about across the mud surface, straining to observe some of the bacterial films in the faint light of early dawn. I don't know exactly what sense was involved, but it seemed very efficient at picking up life forms, even the ones that I need a microscope to observe. "I thought you said this place had a low diversity of species," he remarked. "There are all sorts of organisms here."

"You're right, there are many species living in the estuary. But compared to say, a tropical rainforest, the diversity is 'relatively' low. The species that do live here are beautifully adapted to their environment."

The tide was beginning to cover the mud around us, bringing to life a whole world that had been waiting to resume its activity. Clam siphons appeared at the openings of holes. Burrowing anemones spread their tentacles hoping for a little plankton or detritus to come by. Mud snails and bubble shells plowed across the mud surface, searching for food. A mud shrimp emerged from its burrow, dumped its load of excavated mud and quickly disappeared again.

The Nemartian noticed the water lapping up against his landing gear. "I suppose I'll need to take off soon," he sighed, sounding rather drained.

"You can't leave yet! We're just getting to the interesting part." I held out a tiny yellow egg sack, filled with strings of snail

eggs. "All this talk -- of tides and salt water, substrate, bacteria, productivity -- it's all just setting the stage for this **community**. This unique assemblage of plants and animals is perfectly adapted to the habitat. Each has a specific role to play, but all are connected and interdependent.

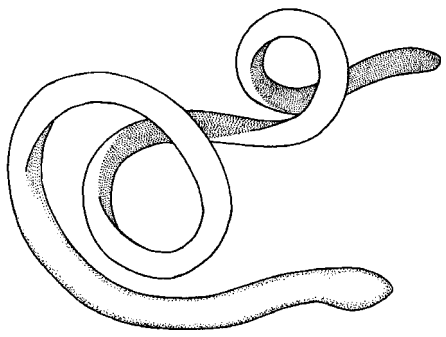
"Just look at this mud shrimp, *Upogebia pugettensis*." I couldn't believe I remembered its scientific name. "That burrow is probably a foot or two deep and is connected to a network of tunnels with turnaround chambers and several openings to the surface. All sorts of animals make use of the mud shrimp's excavation skills. Clams, crabs, worms, even some fish share its burrow. The relationships are complex, and no one knows exactly what goes on in the mud community. It's a fascinating mystery!

"And just ten feet away, right behind you, is a different community, the eelgrass bed, full of organisms that are especially adapted to eelgrass. There's a fish called a pipefish that is skinny and green and swims vertically, aligned with the grass. The eelgrass isopod is shaped like the grass and is perfectly camouflaged. Look, here's a green sea slug that even has stripes that imitate the eelgrass. Its eggs are clear and laid flat against the blade so that even the sharpest eyes can't find them.

"Each community out here has its members: producers, grazers, scavengers and carnivores. No two members occupy exactly the same *niche*. It's truly incredible to see how the whole system fits together. You'll just have to come back to get the rest of the story."

The tide was now well on its way in. I was standing in about six inches of water and remembered that I had that big biology test in just a few hours. "Well, thanks a lot, earthling," the Nemartian squeaked. "It looks as if I'd better be heading back to Stasis." The proboscis began to invert back into the space craft when it seemed to notice something on the mud surface nearby. It suddenly whipped out to full length and focused on a ribbon worm that was just a meter or so from my left foot, crawling along the surface in that characteristic manner. "On second thought, there is time for you to describe this one last animal, for it is without a doubt the most beautiful, graceful, intelligent specimen I have yet to see here. Would you mind?" the Nemartian asked.

"I don't know. I'm feeling pretty tired," I said, "but I'll try. That is *Paranemertes peregrina,* commonly called the ribbon worm. It belongs to the animal phylum Nemertea. Nemerteans are typically creeping or burrowing worms with soft bodies covered with cilia. They are highly contractile and some of them resemble rubber bands. They are not rubbery in texture, however. In fact, if you're not careful, they will easily break when handled. They range in size from a few millimeters to 3 meters! Nearly all nemerteans are fierce predators. They eat other worms, molluscs, and crustaceans. Some swallow their prey whole while others suck out their juices.



Ribbon worm (*Paranemertes peregrina*)

"The reason such fragile animals can be such fierce predators is that they are armed with a formidable proboscis. It is often larger than the actual body of the worm and is sometimes armed with a sharp barb that operates in conjunction with a venom gland to capture or quiet prey.

"I once placed a nemertean in a dish of seawater with a much larger and seemingly meaner mussel worm (*Nereis*), expecting the worst to befall the ribbon worm. To my surprise, the nemertean's probing proboscis stung the mussel worm, inflicting such pain that the victim writhed for several minutes before escaping to the other side of the dish. Later I learned that some nemerteans prey on these large mussel worms, which are formidable predators in their own right, and swallow them whole after subduing them."

Again, I can't explain just how I sensed this from the expression of a proboscis, but the Nemartian seemed to glow with pride after hearing this story.

"Nemerteans are tough, too," I continued. "As I said before, they have a trait of breaking apart when disturbed. At least some of these pieces will regenerate into complete animals. One study showed that pieces one-hundred-thousandth the volume of the original would continue as miniature worms. In other words, a worm 1/8 inch in diameter could be cut into 1/16 inch slices and all the fragments would regenerate."

"That's disgusting! You humans are sick," said the Nemartian.

"I'm just trying to emphasize how durable these animals are," I countered. I don't know why, but I just couldn't resist pushing the Nemartian's buttons. "They have also tried freezing adult worms and have found that they survive. They have starved some species for more than a year and again, the nemerteans survived. The worm may shrink in that time but it will not die."

"That does it, I'm out of here!" And with that as its parting words, the Nemartian inverted its proboscis into the space craft, slammed the door and, before I could even get to my feet, rose up and vanished in the pale dawn sky.

My next recollection was awakening in my car, parked at the beach. I rubbed my eyes and squinted out at the rippling water that now covered the mudflat. What a wild dream, I thought. I must have been so worried about this biology exam that I dreamed about it. Well it serves me right for not preparing. But still, what a wild dream! I returned home
quickly so that I could change clothes and get to school on time. When I opened the trunk to get my things, there were my hip boots, covered with wet, estuary mud.

So, what do you make of that?

Related Activities:
Taking An Estuary Field Trip, Activity 1.

Plankton Study, Activity 2.

Water Quality Monitoring, Activity 3.

Keeping a Marine Aquarium, Activity 4.

See also:
A Field Guide to Padilla Bay Organisms

Questions
1. What watershed do you live in? What river or body of water does it drain into?

2. Name two ecosystems that are associated with an estuary ecosystem. In what ways are they associated?

3. Explain why it might be difficult for an organism to live in a place that has tides. Explain how it might be advantageous.

4. Why is detritus more nutritious than the dead plants and animals it is made up of?

5. Which produces the most oxygen in one year: an acre of forest, an acre of hay, an acre of eelgrass? Which produces the least?

6. Why did the Nemartian cross the universe?

7. Why do some organisms living in salt water need a strategy to avoid dehydration?

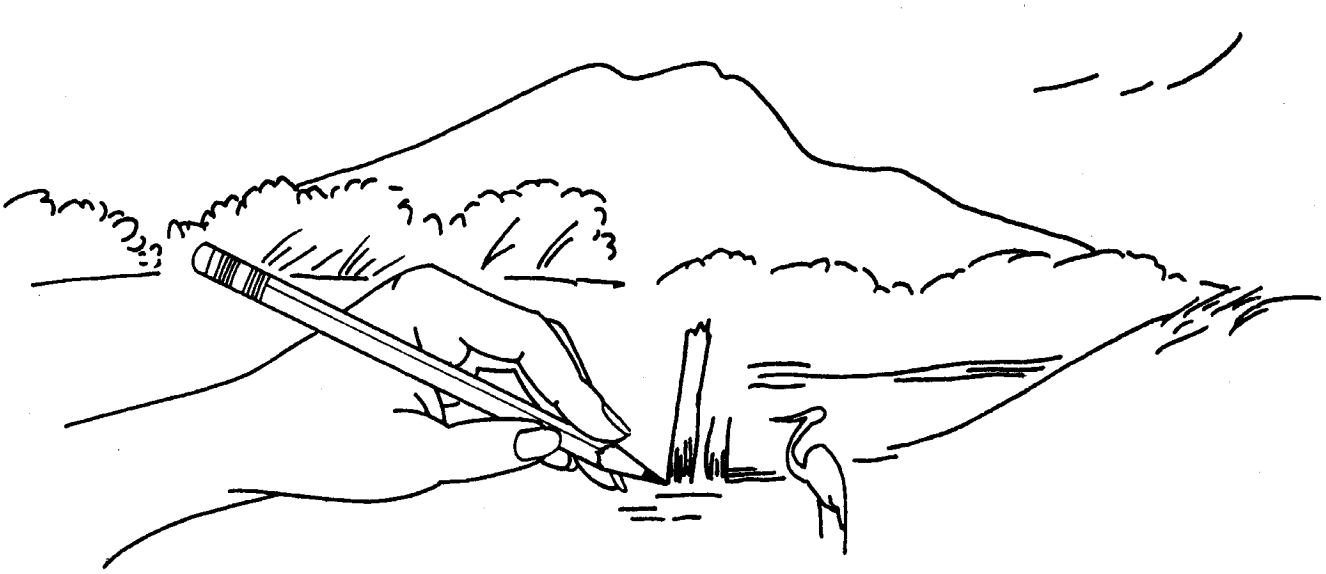
8. How are *Zostera* species examples of adaptive radiation?

9. How did *Zostera japonica* first get into Padilla Bay?

10. List three values of eelgrass.

11. Why are bacteria important in estuaries?

12. Name three ecological communities found in Padilla Bay.



4 - Estuary Inspired - Literature and the Arts

"There are good things to see in the tide pools and there are exciting and interesting thoughts to be generated from the seeing.

"Every new eye applied to the peep hole which looks out at the world may fish in some new beauty and some new pattern, and the world of the human mind must be enriched by such fishing."

- John Steinbeck, from the introduction to ***Between the Pacific Tides*** by Edward Ricketts and Jack Calvin-

John Steinbeck, a great American writer, wrote this while on a marine biological expedition in the Sea of Cortez with his scientist friend, Ed Ricketts. He says that inside each of us are the skills of a scientitst or an artist capable of looking through the peep hole at life, and seeing something. What we **see**, and how we **express** it is our gift to humanity. He looked into the tidepools and was inspired to write a book about the worlds he saw within them. What do you see? What is your gift?

As people, we have been defined by our landscape. America's human history is the history of our interaction with the land and the water. The oral history of the Native American people tells stories of the land and the water. Our school history books are filled with the European settlers crossing the Atlantic, blazing through the Cumberland Gap, busting sod on prairie homesteads, and fighting for the natural riches of the Pacific Northwest, Alaska, and California. The land is our cultural as well as our physical heritage.

Today we spend days, even weeks indoors. We go from building to car to building as we drive to the mall, the theater, school, and the grocery store. Living in a suburb of Seattle is much the same as living in Akron, Ohio, or Sacramento, California. The stores are the same. The television shows are the same. We're so busy that we sometimes forget to appreciate our home; the land and water in our own backyards.

For many of us, however, the **place** in which we live still makes a difference. It allows us to go backpacking or sailing in our free time. The weather and climate affect our moods and thoughts. The smell of the wet earth, the sight of the mountains or bay leave indelible stamps of places on our minds.

Artists, such as writers, painters, film makers, and musicians remind us of our places. By using nature in their work, they remind us of our connection to the planet, and hold up new images for us to see.

We can still hear the sounds of the primal Pacific Northwest in the myths and stories of the early inhabitants. We can see the world of Walden Pond through the words of Thoreau, the cliffs of Yosemite through the camera of Ansel Adams, the Southwest desert through the paintings of Georgia O'Keeffe. You can't separate the setting from the work, nor can we separate ourselves from what sustains us.

It is natural for people to seek inspiration from nature. Not only for those who produce art, or even science, but for pure sensory and mental gratification. The land is our legacy, and from it our lives are physically and spiritually enriched.

Estuaries, like other natural places, have inspired artists. But more than any other natural environment, estuaries provide deep, instinctual images into our psyche. The roots of both human and ancient cultures are traced to estuaries. The fertile valley of the Tigris and Euphrates rivers is referred to as the cradle of civilization. The Egyptian civilization flourished on the Delta of the Nile. St. Petersburg, Russia's great cultural window on the Baltic, was built on a salt marsh under the cruel leadership of Peter the Great. Rome, London, and New York are just some of the other great cultural cities of the world built on estuaries.

Besides their physical sustenance, estuaries have given us images of peace and solitude, of rhythms and cycles of life, of richness and fertility, and of death and decay.

Death is an often used, and most appropriate, subject for the estuary and the area around it. The estuary is a mud stage where a continuous stream of murders, vicious attacks, and general carnivorous atrocities are enacted. Along with all the carnage comes rebirth as the decaying processes recycle the nutrients back into life.

Dylan Thomas: Estuary Inspired

Dylan Thomas (1914-1953) is one great poet of the twentieth century whose work was strongly influenced by nature and the life and death struggles within an estuary. He was born and spent most of his life in the gentle countryside of southwestern Wales where the Taf and Towy rivers wind their way to meet the rugged coast of the sea. Some of his later poems were written in a boathouse that overlooked an extensive mudflat of the Taf estuary in Laugharne, Wales.

One central theme in his poetry is the never ending cycle of life. He often emphasized the flow from the miracle of birth and creation, through the fierce struggle to survive, to the inevitable passage of death, then back again to birth. He was enthralled with the biological and spiritual realities of life, and he often used the processes he saw in the estuary as images in his poems.

For instance, death is often symbolized by estuary predators like the heron or the hawk, or by *detritivores* like worms.

The Estuary Under Sir John's Hill

Basically, the estuary is not a pretty place to write a poem, so it's no surprise that Dylan Thomas focused on death as he looked across the mudflat and hills of the estuary and wrote his poem *Over Sir John's hill*. (It rains just as much in Wales as it does in the Northwest, so you can imagine how a sunny evening might have inspired him to write a poem.)

Poems have many interpretations, the most important being yours. From the estuarine perspective, *Over Sir John's hill* is a poem mourning the birds and fish preyed upon by predators. It opens with a hawk hovering over a hill at sunset -- above the innocent little birds who don't know what is about to hit them -- until death comes when the "Flash and the Plumes crack." Throughout the poem the poet, as well as the heron, watch all this; the poet thinks of his own death, and the heron simply kills for its next meal.

It is a visual poem in its imagery, but dependent upon sound in its reading. Even if you don't think you understand all of it, read it once aloud. The soft, lyrical melody and light rhyme pattern are a contrast to its dark theme of death. The poet only leaves us clues, the rest is up to us; our vision, our interpretation. Give it a try.

Over Sir John's hill

by Dylan Thomas

Over Sir John's hill,
The hawk on fire hangs still;
In a hoisted cloud, at drop of dusk, he pulls to his claws
And gallows, up the rays of his eyes the small birds of
the bay
And the shrill child's play
Wars
Of the sparrows and such who swansing, dusk, in wrangling
hedges.
And blithely they squawk
To fiery tyburn over the wrestle of elms until
The flash the noosed hawk
Crashes, and slowly the fishing holy stalking heron
In the river Towy below bows his tilted headstone.

Flash, and the plumes crack,
And a black cap of jack-
Daws Sir John's just hill dons, and again the gulled birds
hare
To the hawk on fire, the halter height, over Towy's fins,
In a whack of wind.
There
Where the elegiac fisherbird stabs and paddles
In the pebbly dab-filled
Shallow and sedge, and 'dilly dilly,' calls the loft hawk,
'Come and be killed,'
I open the leaves of the water at a passage
Of psalms and shadows among the pincered sandcrabs
prancing

And read, in a shell
Death clear as a bouy's bell:
All praise of the hawk on fire in hawk-eyed dusk be sung,
When his viperish fuse hangs looped with flames under the
brand

---

swan song: legendary last utterance of a dying swan. **halter:** a rope used for execution by hanging.
blithe: carefree, cheerful. **elegiac:** A mournful poem, composed to lament one who is dead.
-burn: a small stream, in Scottish language. **dab:** any of a variety of flatfishes. To poke.
Towy: a river of southwestern Wales. **psalm:** sacred song or hymn.
jackdaw: Eurasian bird resembling a crow. **brand:** a mark formerly burned in the flesh of criminals.

Wing, and blest shall
Young
Green Chickens of the bay and bushes cluck, 'dilly dilly,
Come let us die.'
We grieve as the blithe birds, never again, leave shingle
and elm,
The heron and I,
I young Aesop fabling to the near night by the dingle
Of eels, saint heron hymning in the shell-hung distant

Crystal harbour vale
Where the sea cobbles sail,
And wharves of water where the walls dance and the white
cranes stilt.
It is the heron and I, under judging Sir John's elmed
Hill, tell-tale the knelled
Guilt
Of the led-astray birds whom God, for their breast of
whistles,
Have Mercy on,
God in his whirlwind silence save, who marks the sparrows
hail,
For their souls' song.
Now the heron grieves in the weeded verge. Through
windows
Of dusk and water I see the tilting whispering

Heron, mirrored, go,
As the snapt feathers snow,
Fishing in the tear of the Towy. Only a hoot owl
Hollows, a grassblade blown in cupped hands, in the looted
elms
And no green cocks or hens
Shout
Now on Sir John's hill. The heron, ankling the scaly
Lowlands of the waves,
Makes all the music; and I who hear the tune of the slow,
Wear-willow river, grave,
Before the lunge of the night, the notes on this time-shaken
Stone for the sake of the souls of the slain birds sailing.

dingle: a small, wooded valley.
knell: to ring or sound a bell in sorrow, especially at funerals.

The Short Story

Look now at another form of writing that has used the estuary for inspiration; the short story. *"The Salt Marsh"* illustrates the power an estuary has to tell a story. This story is based on the events of an estuary in Maine.

The Salt Marsh

by Floyd C. Stuart

I rolled down the car window as I sped through the dark, sucking in deeply the aroma of salt marsh, elemental and frank, to drive the odor of perfumes out of my head. Earlier that evening I had strolled through acres of the Maine Mall, in South Portland. Fumes of exotic soaps and powders and colognes filled the department stores, an olfactory summation of a glittery, titillating way of life that I have grown unused to.

I rubbed elbows with customers, handsome and trig, who seemed to accept video games and personal computers as everybody's norm. From a balcony I gazed up at mobiles floating high above the main level; I bowed my head and meditated on the cleavage of a girl selling watches and rings. The colors and lights, the inexhaustible merchandise and milling people, were exciting. Plaster men and women as young and perfect as I should have been gestured to me, suggesting what I needed. At every turn mirrors showed me what I was. On the sides of the escalators they reflected a dozen pairs of suede casuals, gold-strapped sandals, and high-powered racing sneakers. I got dizzy and left.

The road I took back to my motel passes through a salt marsh -- a fragrant, 3,000-acre blackness that winds toward the vaster blackness of the North Atlantic. A marsh smell is nothing you convince anyone about: it is either the stench of putrefying garbage or a tangy whiff of pure existence.

I slowed the car and breathed in a subtly blended essence of spartina grasses; mud rife with bivalves, annelids, and algae; a hint of iodine; decaying vegetation, fish, and crabs; and, because this is an unpolluted marsh, only the normal tinge of the rotten-egg smell of hydrogen sulfide. The headlight of the car cut the dark in half. For the moment I was alone on the highway that strikes across an inland narrowing of the marsh. The honest smell untensed me, and suddenly a dead man flitted through my mind. A few springs ago he had been found here, stuffed in a plastic trash bag. The police had indentified the victim as an older "transient." A bum. They would never know who had killed him, or why.

A salt marsh is a continent's vacant lot, almost a non-place, where we dump garbage from our industries and murders. But left to itself, a marsh is a clean space: flushed out twice a day, chock-full of bacteria fastidiously dicing up what has died into a detritus for larger creatures to dine on too. The tides are a feast, bringing in guests from the ocean deeps, uncovering delicacies for herons, egrets, and gulls. Biologists have estimated that about two thirds of all marine life is dependent on estuaries and marshes. Acre for acre a salt marsh is one of the most productive habitats there is. The faint odor of death is a reality of a marsh; that perfume clings to all our lives.

On my way back from the mall I drove over a culvert. Below me the swiftest of the marsh's three rivers ran toward the sea. Near here, a year or two before the murdered bum was found, a twenty-two-year-old woman, driving alone late at night, had gone straight where the road curved right. The car neatly missed the guardrail and rocketed into blackness. The woman probably had fallen asleep at the wheel. She slumped for a whole summer and part of an autumn in her overturned Honda on the bottom of a particularly deep tidal channel. The water in a salt marsh is a soup of silt, spartina bits, dead crabs, seaweed fragments, yearling eels, and flecks of mussel shell. You cannot see far in. Search helicopters hovered above the Honda and missed it. Not only was the turbid water deep, it was also the color of the overturned vehicle.

The young woman had been going to visit her boyfriend. For a summer and a fall the hulls of canoes floated above her like dark clouds: children and fathers, solitary bird watchers, lovers preoccupied with each other. One morning in October, after a severe storm that must have ground the Honda onto a shallower bottom, a passing driver spotted the upside-down car in the channel. Later, subtle traces of tire tracks were discovered where the car had crossed a length of marsh before plunging into the water. Hood, tires, grille, head lamps--all were encrusted with barnacles. The dripping car that emerged from the tidal channel looked more like a creature of the marsh than of a mall parking lot.

I kept awake on my drive to the motel. The tide reached its height, hesitated, and then started flowing out, a great, cleansing respiration that must have made my deep-sleeper's breathing in the rented bed seem frenzied and ephemeral.

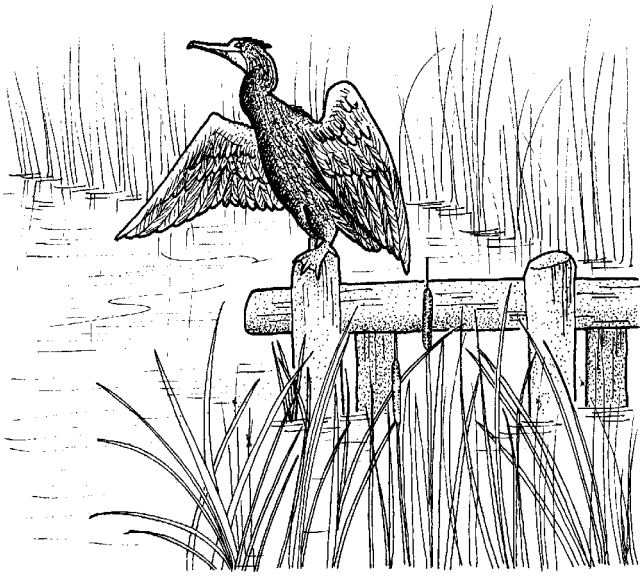
I was back on the sunny marsh by mid-morning, ten-power binoculars slung from my neck, a dime-sized, fourteen-power magnifying lens in my pocket, and two flower books and a bird book in my hand. It was well into September, when an autumn chill should have been upon the marsh. Sweat beaded on my forehead. There was no breeze, and the temperature seemed headed for the nineties.

We do not come to the marsh to hay anymore, driving horses fitted with wooden bog shoes onto the sopping ground. We do not heap teepees of hay on staddles -- clusters of ash pilings pounded into the marsh to make a platform so that the ricks won't float away on the higher tides. One can still find staddles: they are about two feet high, and below ground level the wood is as sound now as the day it was cut, although many staddles are more than a hundred years old. We do not fetch hay off the staddles when the mud has frozen into firm road for teams and wagons. At dusk the white-tailed deer still drift out to graze. We no longer sneak onto the marsh to slaughter by the thou-

sands curlews and golden plover. Our lives have changed. But we do return, and launch our canoes into the sinuous tidal channels, or watch egrets waft upon the marsh like blank pages torn from a notebook. We glide past delicate sprays of sea lavender blooming atop the muddy banks. And during a summer hundreds of us, by ones and twos in our canoes, ghosted above a speechless woman crumpled in a Honda. We paddled toward the North Atlantic and back, and could not see.

The last of the tide was going out when I walked onto the causeway, an abandoned railroad bed that crossed the mile-wide marsh. The waters of the main channel were sucking noisily at the causeway boulders. On the high marsh *Spartina patens* often makes cowlicks -- swirls of flattened grass where the marsh beasts seem to have bedded down for the night. This is the way this spartina does, bending at a curious weak spot near the base of the stem and leaning on its neighbors. In the morning light the cowlicks are brushed-silver medallions among the greener standing stems. The spartina is anchored in mud and its own decayed past, and neither sea nor the fist of man could easily uproot it. Stray hurricanes, the steady battering of winter storms, and the grinding rafts of ice loose upon the tides do not, in the long run, change the marsh very much. The mud and the spartina with its weak spot are too powerful for mere wind and waves. Storm-gored, the marsh heals itself. And we come, transient, not well adapted to the harshness of existence, as though here, in the strange, rustling grasses between sea and land, we might learn to heal ourselves.

I looked at birds and at what was growing along the causeway, refreshing a memory that is sometimes dulled by inland living. I stooped to seaside goldenrod. The bulbous pods of sea rocket, a common mustard, stopped me in my tracks. I sat down in the dust and thumbed my guidebooks, dotting the pages with sweat. Something fragrant, maybe a kind of sage, distracted me, and then two more plants that I could not identify; I am clumsily self-taught. A firehouse siren cranked up and I heard it, but not with any conscious attention. A cormorant beat by, silent as always, his yellow chin patch flashing. We still follow the usage of the early English settlers of this coast and call the bird a shag. He lighted on the top of a utility pole at the footbridge and stretched his scrawny wings to dry. This salt marsh is incomplete without a black shag cross nailed atop that particular post. Shags are swift and lethal swimmers beneath the sea, and because they do not secrete waterproofing grease upon their feathers, as ducks do, water weights them down so that they can dive more readily. But now and then the burdened shags must perch on ledge or buoy or piling and hold out their wings to the wind.



I sat in the dust and dripped on my books, snatching glances at the shag through binoculars, squinting at anthers and filaments waving into the magnifying lens like the arms of a giant squid. Sometimes I paused, and laid my lenses aside, and saw how circumscribed the world was. The green line of woodland across the marsh arced to distant highway and swept behind the culvert into scrub, which bent to the sandy spit in the brilliant haze where ocean and marsh touched. Twists of land concealed the North Atlantic.

The wallop of sirens, insistent and multiple, broke my trance, and I looked up from my flower book. A car towing a camper was parked on the gravel shoulder by the culvert that I had driven over the night before. A pickup was stopped nose-to-nose with the car, but the two vehicles did not appear to have collided. The road along the rim of the marsh was deserted except for a small yellow pickup parked near the guardrail on the other side of the highway. A bar of blue lights stuttered atop the cab. A policeman leaped the guardrail and disappeared down the farther bank. A few seconds later he shot up, dashed across the road, and scrabbled down the weedy bank to the culvert as if he expected something to flume through. Cars were pulling off the highway -- thirty within a few seconds, it seemed. Some people were gawkers, but others leaped down the bank as if they had business. They peered up the culvert and then focused their attention on the water in front of it. All the while the sirens whooped. The higher-pitched ones belonged to approaching vehicles, but a throatier, incessant honking came from the fire station, a few miles off. Red and blue lights glittered along the highway from both directions.

I watched real life -- whatever it was that was happening -- and yet a restricted life, in a neat binocular ring. The tide was nearly out, and the green-slimed remains of an old wharf or a bridge, which earlier that summer I had canoed over during high tide, jutted out of the mud and the narrowed channel. Beyond the rotten pilings the channel makes a broad loop, parallels the highway until it reaches the culvert, and then swings out of sight behind spartina. At high tide, water had nearly licked the roof of the culvert, which is about eight feet tall. Now a frothy gush a couple of feet deep -- still too emphatic for a man to stand up in -- pulsated out of the shadow. The policeman stood in street shoes on the muddy shore, peering into the deep pool in front of the culvert.

A young fellow in blue jeans and sneakers, and naked to the waist, waited docilely, like a girl letting someone hem her dress, while two other men tied a red lifeline at the small of his back. Then he eased into the pool beneath the culvert waterfall, adjusted his snorkel mask, and floated on his face just under the surface of the water, like a corpse. His companions held onto his red umbilicus for dear life. From somewhere outside the circle of my binoculars men kept spilling down the bank. Suddenly the scene stalled -- silent men lined the shore, the red tip of the snorkel tube was stationary in the pool, spartina blades were quiet in the heat -- and yet one sensed a tremendous urgency. On the bank a man in a T-shirt, slacks, and sneakers waited impatiently while others checked the air tank on his back and fastened a lifeline around his waist. The snorkeler rose out of the pool, stooped and dripping, and spoke briefly with the scuba diver, and then both of them slipped beneath the water.

Crooked lines of cars now littered both shoulders of the highway for hundreds of feet in either direction from the culvert. It

looked like a chain-reaction accident on a freeway, and yet amid all the apparent confusion emergency vehicles moved quickly and efficiently. A fire truck roared up, and although several men were in uniform, most of the men clambering on the bank or holding lifelines were in civilian clothes. It was Sunday, and several men standing in the mud wore white shirts and slacks, as if they had rushed out of church. Volunteer firemen, I guessed, remembering the blatting fire-station horn. Down the straight reach of highway an ambulance wove between the parked cars, its flashing lights faded in the sun, its siren sounding louder and louder. The white box shimmered in the heat, as if the pitch of its own siren were melting it. I swung my binoculars back up the road, and from a seaside town came a fire engine towing a lifesaving raft -- a sight not incongruous on our coast.

I could only guess at what was going on. I was sitting in the midst of exciting events and yet was isolated at the edge. A silent hammer of heat beat upon my head and shoulder blades. For protection I put on the drenched T-shirt I had earlier peeled off. Insects leaped from cupped umbels of Queen Anne's lace and from stalks of grasses, crisscrossing my lap, flitting onto my anklebone, or resting a moment in the shelter of my cutoff blue jeans. A diver's arm smacked water and I saw the spatter of silver splinters, but I heard at this distance only the September buzz of insects: nothing ends, ever ends, ends . . .

The men were fighting vicious seconds to rescue someone under water; and they were just tiny figures in the tableau of living and dying, nothing new under the pelting sun.

At night the marsh lures us into accidents; it wraps dark arms around our murders. In the light of day we sometimes discover what has been done. At two o'clock one morning twelve years ago, a forty-year-old businessman was driving through the marsh on his way home. One car was ahead of him. Without warning it swerved off the road, crossed twenty or thirty feet of marsh to a pool, and tipped upside down into it. The tail lights still glowed as the car sank in ink. The businessman skidded to a stop, plunged into the chaos of the night marsh, and struggled toward the disappearing car. "I went up to my shoulders," the good man said later. "It was like quicksand, half water, half mud." The car was completely submerged when he reached it. And yet somehow he saw an arm dangling out the driver's window, and long hair flowing in the water. He seized them and tugged with all his might, yanking a nineteen-year-old girl into new life on the marsh that night.

The rescued girl's mother said that her daughter had fallen asleep at the wheel. "She was thinking of how good bed would feel... She woke up in the marsh. She took a gulp of it and didn't know where the car window was." The businessman staggered out of the marsh with the girl, her head gushing blood. Several motorists had stopped and watched him fight to save the victim, but they did not help. The businessman shouted for someone to call an ambulance. No one would. He slogged onto the highway and civilization again. His arms were full of crying girl, and he asked the bystanders to open his car door. After a while someone did. He drove her to a state-police barracks. Later he apologized to the girl's grateful parents for having had to drag her out by her hair and arm, and said that he hoped he had not hurt her. The marsh had given the businessman tonsilitis.

The firemen were swift. They slid the raft off the trailer, and half a dozen of them lugged it down the bank like a coffin, gripping the yellow rope looped along the black sides.The raft had a rigid bottom, about

eighteen or twenty feet long and six feet wide, which was rimmed by an inflated rubber tube that came to a point at the bow. From the open stern the raft looked like two torpedoes with a great white outboard motor slung between. The name of the fire department and MARINE 4 were painted in bold yellow characters along the side. The men moved almost tenderly, launching the raft, guiding it clear of the divers. A puff of blue smoke kicked up from the motor, and wafted off.

For a long time, it seemed, nothing happened. The divers disappeared at intervals, the scuba diver for longer periods. No one yelled or moved abruptly. The half-dozen men stood on the raft, watching red lifelines slackening and pulling taut upon the pool. Policemen and firemen had raced here to save a life, and now they could not even dredge up a corpse. I let the binoculars dangle against my chest, bored by a hiatus that would have been edited out of telelvision news. Across the channel a line of gray utility poles stood beside the causeway. On each of the first ten a herring gull was perched like a flagstaff ornament. Waiting, for gulls, *is* the grand event. Nothing happened at the culvert for a long, long while -- two or three minutes, at least.

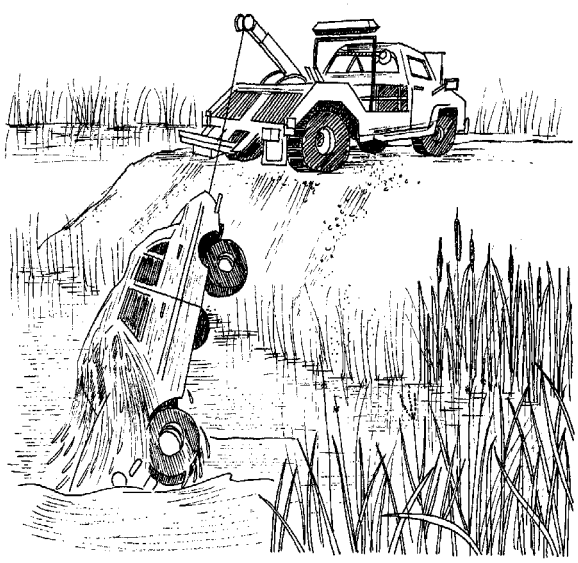
Thudding heat and droning autumn insects correct one's perception of time. Three thousand years -- the lifetime, so far, of this marsh -- is barely a start. This is a sunken coast springing back since the tremendous weight of the last glacier melted off. From Cape Elizabeth north, the State of Maine littoral is abrupt headlands and surfacing island mountaintops; it is drowned river valleys become scraggly inlets and bays. A dozen thousand years is nothing: on our upstart coast post-glacial erosion hasn't really had a chance. The heat, new since the last ice age, beat upon me as I sat in that fledgling marsh. Above, the sky was blue pigment diluted with milk. The haze had bulk; the glare pressed like the ice sheet that a short while ago had been a mile or two thick. The small sound of traffic muttered at the edge of things. Cut off from where human life was taking place, I learned a new kind of time. A mussel secreted a layer of its shell. Granite mountains deep in the interior eroded grain by grain and flowed down coastal currents, silting-in a bay, beginning a marsh. In the stasis of droning insects I thought that all of this was happening too fast.

A perfume-counter smell hit me, ephemeral and as hard as concrete. I suddenly imagined, with the wholeness of a vision, a girl perched on the edge of her bed, intent and serene, resting her chin on her bent knee. She brushed a crucial swath of polish on the nail of her little toe. In the same second, inconsequential in the great grinding-down of the universe, a green wrecker backed as far as it could onto the bank beside the culvert, and stopped. Men unwound a steel cable from the winch and dragged it to the water.

Our comings and goings upon the marsh -- restorative, quotidian, urgent -- and the marsh itself are motes floating in a shaft of geologic time. We can be disposed of in a trash bag or a little car. We contain light years of courage and love. We refuse to help. The mother of the girl that the businessman saved told a reporter: "I can't explain or say what I feel down deep. . . Without him, she'd have drowned. We wanted people to know." We are so vast and small, so much at home in this place where we are lost. Maybe it is not remarkable, then, that we sometimes say what can't be said.

Droplets sparked off the cable as it tautened. I put the circle of my binoculars upon the empty pool with the length of rusty cable sticking in it like a spear. The point hit inside a V of steady ripples. Then the surface of the pool was disturbed; the V of ripples

wobbled and broke. A silver bumper bulged into the air, water gushing off. The wrecker slowly drew from the channel the trunk of a



Mercedes. The divers treaded water around the car like curious seals. The rear window was gone, and I could see a shallow dent in the rear of the roof. Half the car was now suspended on a thread from the boom of the wrecker. The Mercedes's rear wheels hung from extended shocks like slack jaws. A waterfall tumbled off the roof, and men shoved into the ring of my binoculars, trying to peer into the car windows, which were blurred by saltwater greasiness. The Mercedes was an oxblood color accented by a sexy gold stripe slong the side. I looked for slumped bodies inside, but glimpsed only slabs of daylight through the windows and between men's backs as they huddled around the passenger compartment. The wrecker hauled the car well up onto the bank. Someone opened a door, and water spilled onto his feet. The men gingerly bent in. When they stood back, I could see: nothing. A fireman scraped a handful of ooze off the plush seat and slopped it into the channel. The Mercedes, elegant and slightly dented, leaked and leaked. I wondered where the rear window was. Compression might have popped it out at impact; or maybe the scuba diver had used equipment I had not seen to pry it free. He did not retrieve the window from the pool. The men looked forlorn, at loose ends. They were used to saving lives and seeing death. They were not sure what to do with this. The empty Mercedes spread its doors like wings and squatted on the bank. The shag on the utility pole at the causeway footbridge tilted his beak in the snooty way shags do, and gazed elsewhere. The crowd melted from the guardrail. The rows of awkwardly parked cars were suddenly gone. Someone slammed the ambulance doors shut, and the white box turned around and went back. The red lights stopped flashing. Fire trucks disappeared, even the one towing the trailer. I put the glasses on MARINE 4, and the lifesaving raft put-putted down the channel toward me, the six men standing up and watching the water. The top of a two-way radio and a telescoped antenna stuck out of one man's hip pocket. Even when the light was right, you could see only a foot or two into the sediment-laden channel. I swept the glasses upstream again: the wrecker and the Mercedes were gone, and the guardrail was deserted. All signs of human life, it seemed, had been sucked up the black hole of the culvert.

The men on the lifesaving raft passed me and disappeared around a bend in the tidal channel, seaching for bodies that might have been carried toward the open sea. A car pulled up on the shoulder by the culvert, and two young men took a canoe off the roof. They launched it into the channel, innocent of the excitement they had just missed. They dipped their paddles and scanned the banks. They seemed to think that the world was new, and that they were the first human beings astir in it.

Was it murder, suicide, death by accident, or simply a stolen car? The searchers standing on the lifesaving rafts explored the loops of the tidal channel. Once, their row of severed heads glided along a horizon of spartina like targets in a shooting gallery. Then they were lost for good. I wondered idly if in a hundred years the cement stumps of the mall would be as well preserved as the staddles in the marsh.

Grain by grain the mountains come down: little murders of ourselves and others, misadventures, stolen moments. Out toward the ocean the air was golden and kind of blue, thick with pollen, it seemed, and a powder of steel filings. It trembled a bit as if the world out there were on a shaky footing. A pinhead of light glittered on the spit where cottages and a tarred street ended abruptly at the beach. At first I thought the pinhead was a glint of anything -- car window, waves. But it was red and rhythmic. Out on the last land the dome light of a fire truck flashed -- the pulse of lifesavers doing the humanly possible. The firemen waited for their friends on MARINE 4 and what they might have found. Beyond the shimmering point lay nothing but the rumored Azores.

Related Activities

Taking an Estuary Field Trip, Activity 1
Writing With Estuaries, Activity 5

See Also

Estuary Arts and Literature, Resources Section

Questions

1. Why do you think so much human history is related to these obscure places called estuaries?

2 .How do artists affect the way we see things?

3. Think of your favorite movie. How does the setting affect the characters? How does it affect you, the viewer?

4. Dylan Thomas gives us many estuarine images in his poem, *Over Sir John's hill*, including images of life, death, and renewal. Pick a phrase, word, or line from the poem and describe the image it inspires for you. Try to find this image elsewhere in the poem.

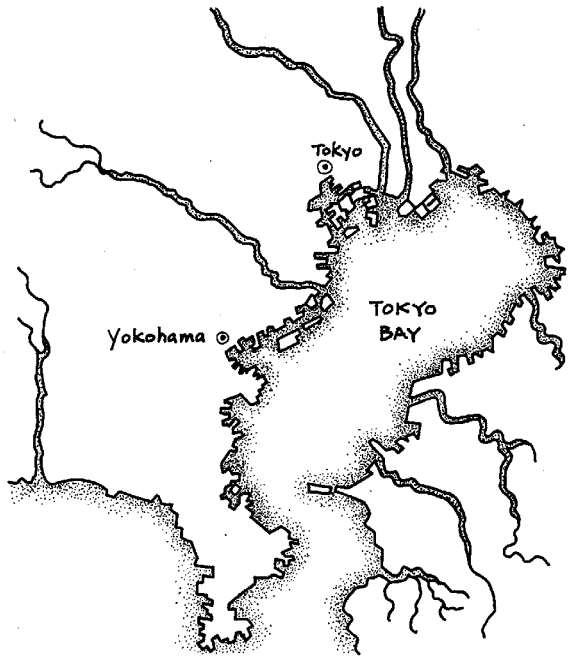
5. Floyd Stuart writes "A marsh smell is nothing you convince anyone about: it is either the stench of putrefying garbage or a tangy whiff of pure existence." Which way do you think Mr. Stuart feels? Provide quotes to justify your answer.

6. Find two references in *The Salt Marsh* to images of death and two images of birth, renewal, or productivity.

5 - Estuary Developed - Human Uses

People around the world have been using estuaries since prehistoric times. They have been attracted to the abundant food resources in estuary waters. They have taken advantage of access to waterways for travel and moving goods. They have farmed the surrounding fertile land, and have learned to love the estuary's quiet bays and flourishing wildlife. They have also left their mark on estuaries. They have dredged, filled, developed and poisoned estuaries so that sometimes the environment that attracted people in the first place no longer exists

Many large cities have grown up around estuaries. Seattle, San Francisco, Los Angeles, New York, Boston, Baltimore, Washington, D.C., and New Orleans are all United States cities on estuaries. In Europe, estuaries are the sites for London, Amsterdam, Lisbon, Stockholm, Helsinki, and St. Petersburg. In Asia, the cities of Calcutta, Bombay, Hong Kong, Shanghai, Tokyo, Bangkok, and Manila are some of the hundreds located on estuaries. In most of these cases, deep channels have been dredged for shipping, marshes and mudflats have been filled for housing and industry or drained for agricultural land, and waters have been polluted with sewage and industrial wastes.



The highly altered shoreline of Tokyo Bay.

Many of the world's richest estuaries have completely disappeared and others face continuing pressure from development. Because estuaries are important parts of the larger marine system, this development of estuaries has most likely had a global effect. The decision to alter one salt marsh may seem inconsequential, but the effects will reach beyond its edges. Taken together with losses around the world, the effects can be enormous.

Many different human activities can harm estuaries. The following is a discussion of the activities which have had the most significant effects on the Puget Sound estuary.

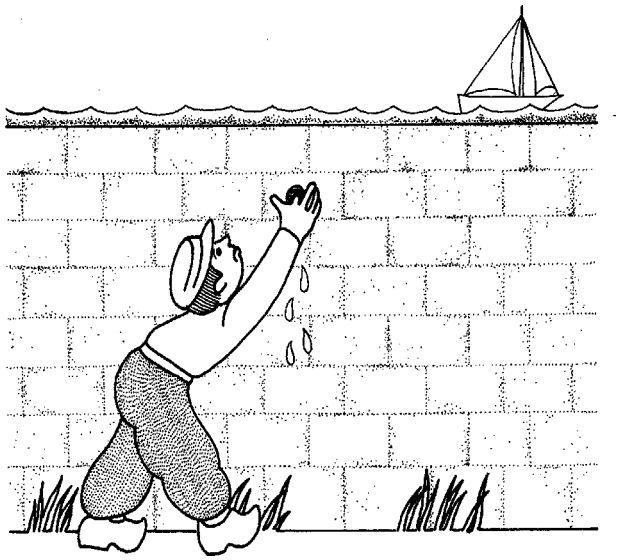
Diking

Since European settlement began in the mid-1800s, most of the Pacific Northwest's estuarine wetlands (salt marshes, swamps, and eelgrass beds) have been lost.

About 90% of that loss was a result of *diking* for agricultural land between 1880 and 1930. The federal Swamplands Acts of 1849, 1859,
and 1860 offered free land to encourage the diking and draining of wetlands, and early settlers found that it was easier to reclaim the tidelands for farming than it was to remove forests and stumps from the rugged upland. During the logging boom in the late 1800s, the demand for oats, hay, and potatoes was high, so farmers could quickly earn enough money to pay for the dike construction.

Early dikes were built by hand, with shovels and wheelbarrows. Most were four feet high and eight feet thick at the base, extending along the salt water side of the claim and as far up the sloughs as the tides reached. The earth for the dike was taken from the "inside" of the dike, leaving a deep ditch for drainage. A tide gate or "sluice box" under the dike allowed water to drain out at low tide, but prevented salt water from returning at high tide. The complex network of channels and sloughs within the marsh were either filled or allowed to become drainage ditches.

Although diking is no longer a threat to estuaries in Puget Sound, it did cause the loss of much valuable estuarine habitat. In some areas, such as the Samish delta, over 90% of the estuarine marsh was turned into fertile farmland. All but about 60 acres of the extensive salt marshes bordering Padilla Bay have been converted to agricultural land. It is important to remember that when people talk of habitat loss today the total remaining "pie" we continue to slice up is a mere fraction of the original habitat.



Legendary Peter plugged a hole in the dike and saved his country from flooding by the sea.

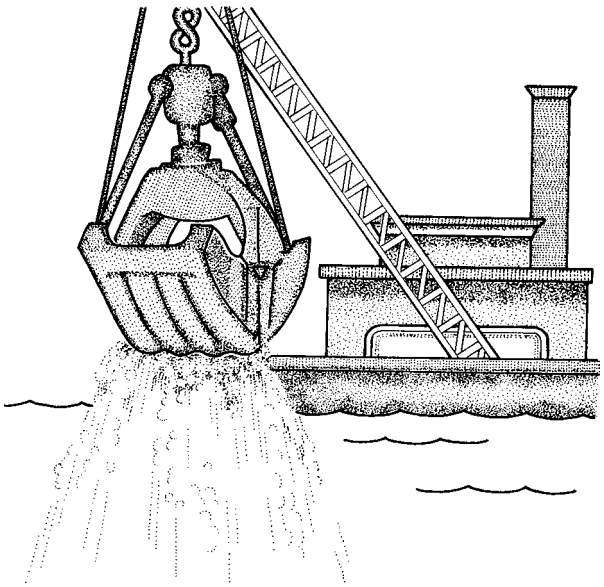
In other parts of the world, diking has been even more prevalent. The Netherlands, for example, began reclaiming tideland in the 1300's. Today, over half of the country's

land area is diked and drained tideland.

Dredging and Filling

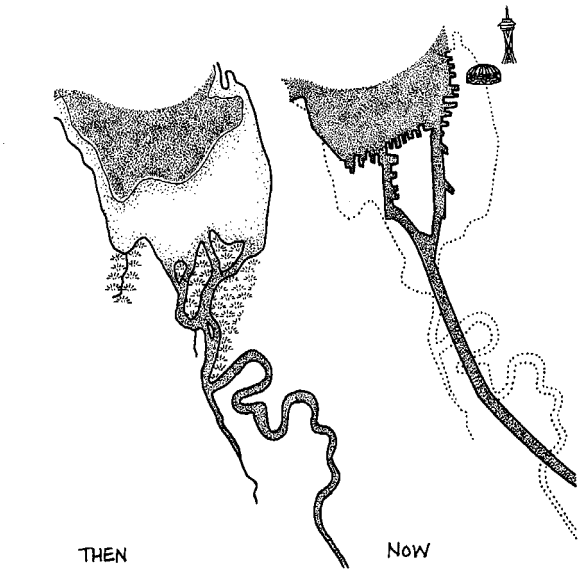
Before the days of *dredges*, people were pretty well stuck (literally) with only naturally occurring waterways. Deep water ports were at a premium and navigation of large vessels was restricted to deep channels and large rivers. Rivers such as the Columbia, whose mouth is blocked by a shifting sand bar, were difficult to navigate, and ships spent weeks outside the bar, waiting for the right conditions to sail through. They often ended up grounded or wrecked.

Dredges -- floating cranes with scoops or "clam-shell" buckets -- changed water transportation dramatically. Channels and



harbors could be dug out wherever needed, making them predictable and safe.

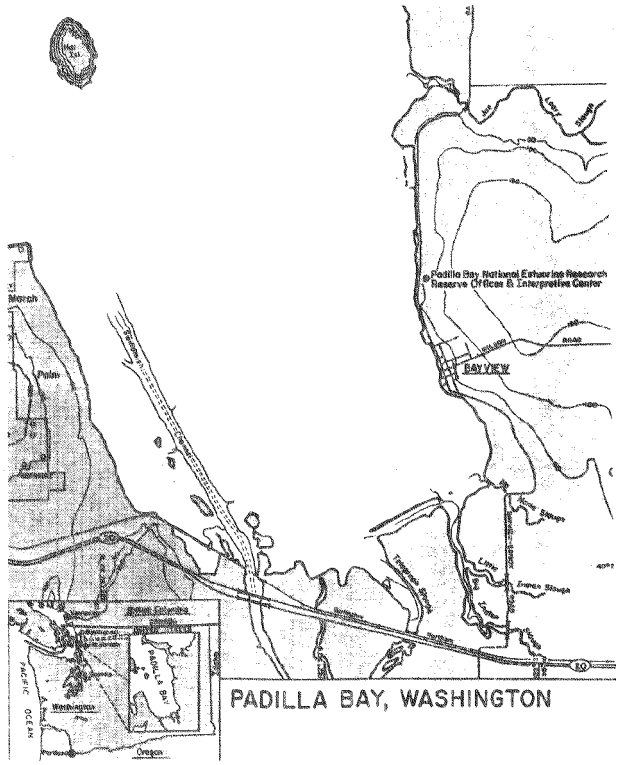
In the past dredging and filling often went hand in hand. Early ports in Puget Sound were often long piers, stretching out across mudflats and marshes to deep water. These intertidal areas, separating the town from the dock, began to be filled with unwanted ballast from ships and sawdust from lumber mills located on the piers. Later, when people began dredging shipping channels, the dredged material was deposited in the intertidal area. It didn't take long before



The Seattle shoreline has changed dramatically in the past 100 years.

the filled area was seen as valuable commercial and industrial land and the "city" moved out to the end of the dock.

At Bayview State Park on Padilla Bay the Washington State Parks and Recreation Commission dredged, not to create deeper water, but to build up a picnic area and sandy beach on the edge of the mudflats. In this case, dredging was the "tool" or the



The Swinomish Channel is dredged every few years.

means to achieving the end -- an attractive picnic site. Though the dredging destroyed an area of intertidal mudflat habitat, it created a pool where eelgrass flourishes.

The Swinomish Channel which flows into Padilla Bay is dredged every few years to maintain a shipping channel. Between 1930 and 1950, the material was deposited in the bay on dredge spoil islands. The islands, now a favorite haul out spot for harbor seals, are by-products of the dredging. Since the late 1970s, all dredged materials from the Swinomish Channel have been transported to deep water disposal sites.

Today, both the shipping and pleasure boating industries in Puget Sound depend on dredging to maintain 50 miles of channels, 50 miles of port berths and 200 small boat harbors. The channels vary from 12 to 30 feet deep, and all must be periodically dredged. For some, dredging every 10 or 15 years is sufficient, while others are dredged each year. The U.S. Army Corps of Engineers maintains most of the major waterways, and accounts for about one third of the dredging activity. Puget Sound ports, as well as small marina owners, private businesses, the U.S. Navy, and municipalities, also dredge.

Past effects of dredging and dredge material disposal have been the filling and loss of intertidal areas such as mudflats and marshes. Dredging can also stir up fine sediments, clouding the water and harming sensitive areas such as eelgrass beds. Now a new problem, contaminated dredge spoils, has emerged.

As disposal sites near the dredging activity have become scarce or are used for other purposes, dredged materials are discharged directly into the Sound. The Washington State Department of Natural Resources regulates eight "unconfined open-water disposal sites" where much of the material is discharged. Some dredged material, however, cannot be disposed of in these sites. It contains contaminants that most likely entered the Sound from industrial or municipal discharge and storm runoff. These contaminants are discussed in more detail below.

When contaminants enter the estuary, they often find their way to the sediment where they bind with the sediment particles. If this contaminated sediment is then dredged and disposed of in an unconfined open-water site, the pollutants are spread to a different area of the Sound and may be released into the water where they pose a greater threat to marine animals and humans. New state regulations require that all dredged materials be tested for *toxic* contaminants. In contaminated areas (often near large, urban centers), dredge operators

must find their own disposal sites, either on land or in a confined site, where the material is capped with a layer of clean sediment.

As land in the Puget Sound area becomes more developed and more pollutants enter the Sound, it is becoming increasingly difficult to find appropriate disposal sites for dredged materials. Testing sediments for contaminants is costly, and some dredging projects have been stopped because of increased costs or the lack of a safe disposal site.

Toxic Contamination

According to some researchers and water quality officials, *toxic* contamination poses the most serious and long-term threat to Puget Sound. Contaminants can enter an estuary in many ways. Industrial discharge, sewage treatment plants, storm drains, septic tanks, and runoff from farm fields and parking lots are some of the more conspicuous sources.

The main toxic chemicals that may find their way into an estuary are heavy metals and *organic* compounds. Heavy metals such as lead, mercury, copper and arsenic may not be harmful to marine organisms in naturally occurring low levels, but in large quantities and certain chemical forms they can accumulate in tissues of plants and animals and cause disease or death.

Organic compounds can be either naturally occurring or created by humans (synthetic organics). The naturally occurring ones are the "fuel" on which the estuary runs. In the proper amounts, they contribute to a healthy system. Petroleum hydrocarbons such as oil occur naturally, and become a problem only when they appear in large quantities. Synthetic organics can accumulate in animal tissues and be toxic. Two well known synthetic organics that persist for years are PCB's (polychlorinated biphenyls) and DDT, a pesticide. These contaminants are still causing problems in marine systems, even though their use has been banned in the United States.

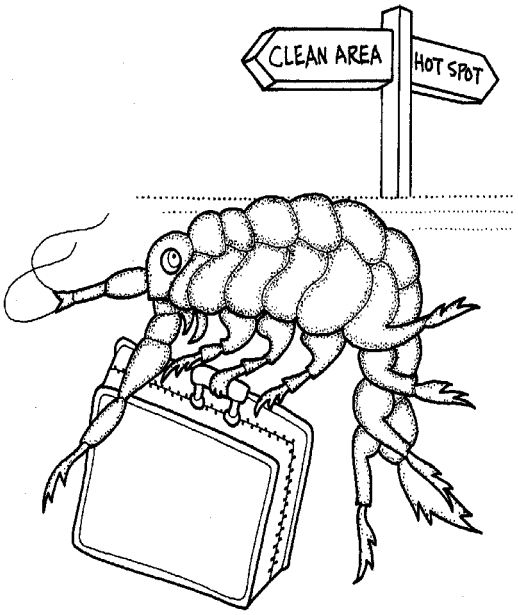
Some of the contaminants that enter an estuary dissolve into the water and are either carried out and diluted with the tide or become a part of the water column food web. Most contaminants, however, bind with sediment particles and settle out as the water slows down and its load is deposited in the estuary. This natural settling makes the estuary especially vulnerable to toxic contamination.

Once in the sediments, the contaminants can cause problems for benthic organisms. Toxic contaminants not only affect the organisms which live in and consume the sediments, but they also affect predators such as bottom fish. Because the contaminants often accumulate in animal tissue, they can be passed on up the food chain to fish like salmon as well as marine birds, marine mammals, and even humans.

In a healthy estuary, a complex community of detritivores performs the role of decomposing and recycling nutrients. If sediments become contaminated, only a few species of organisms, such as worms and molluscs, survive. Sensitive animals such as amphipods are used by researchers as "indicator" species. Their mortality in sediments helps researchers determine whether toxic contamination is a problem.

In Puget Sound, sediment contamination is patchy, so clean areas can occur right next to contaminated "hot spots." Most contaminants have been found around urban areas, where industry and development is most concentrated, but non-urban bays can also be contaminated. A recent

study in Padilla Bay indicated the presence of toxic sediments near an old county dump site. The study involved placing amphipods



Amphipods are especially sensitive to toxic sediments.

in sediment samples collected from various sites around the bay. Those samples in which a significant number of amphipods died most likely contained toxic contaminants.

Contaminants other than toxics also affect estuaries. Excess nutrients (from fertilizers, human sewage, or industries), temperature changes, organic materials that lower the oxygen level in the water, and salinity changes can all upset the natural balances of an estuary. Disease causing organisms can enter from boats, septic systems, sewage treatment plants, pets, and livestock, causing danger to humans using the estuary. Many of Washington's productive shellfish beds have been closed because of fecal contamination.

Though in the past 20 years, regulations have come a long way toward reducing the contaminants entering Puget Sound, the problem still exists. Much of the contamination comes from "non-permitted" sources such as storm runoff -- sources that are difficult to regulate. (Examples of "permitted" sources, those which obtain permits to discharge waste into water, include industries and city sewage treatment plants.)

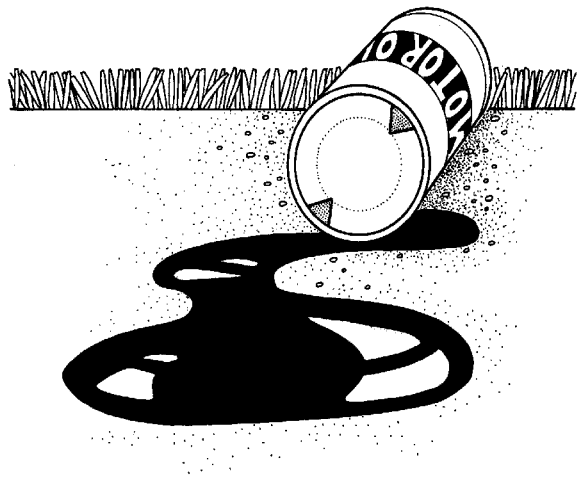
Other estuaries, such as those on the more densely populated east coast and those in developing countries, face much larger contaminant problems. Many developing countries feel they cannot afford to control industrial and municipal wastes. When people are hungry and unemployed, governments are hesitant to impose environmental regulations. The loss of fishing jobs and edible seafood that accompanies polluted waters often goes unrecognized.

"Outside" Influences

Estuaries are not isolated systems. They are connected to both the river and ocean through the movement of water. What happens upstream or in nearby ocean water can have a big effect on the estuary.

Watershed is a term for the area of land which drains into one stream, river, or bay. A watershed like the Mississippi's can include millions of acres and many states. The Skagit River watershed reaches into British Columbia. The Padilla Bay watershed, on the other hand, is only a small area within one county.

Something that enters the water far upstream can eventually find its way into the estuary. Poor logging practices in the moun tains can lead to erosion and too much sediment entering the water. The sediment ultimately ends up in the estuary where it may harm fish and plant life by clogging



gills, slowing egg development, and blocking sunlight. One gallon of used motor oil dumped into a ditch can send toxic chemicals to an estuary miles away. Though rivers and streams have the ability to "clean" themselves with time, rivers can be overloaded, and the water entering our estuaries is often contaminated.

Chesapeake Bay is an example of an estuary whose health is endangered by intense human activities in its watershed. Though about 8 million people live along the bay's shores, over 13 million live within its watershed. When people began the challenge of cleaning up the bay in the late 1970s and early 1980s, they looked not only at pollution sources located right on the bay (sources like Baltimore's sewage treatment plant or industrial wastes) but they also targeted farmers upstream in Pennsylvania along the Susquehanna River, the source of one-third of the estuary's fresh water.

The use of river water for hydroelectric power, agricultural irrigation, and drinking water can create serious problems in the estuary. When people divert fresh water for irrigation, industry and household use, it can lead to less fresh water entering the estuary. This is a problem for many estuaries in the arid southwest. Hydroelectric dams interrupt migrations of salmon and hold back the natural supply of sediment that nourishes the estuary marshes. Flood control levies at the mouth of the Mississippi River have stopped the accumulation of sediments in Louisiana's extensive salt marshes. Without the constant supply of sediment, the marshes are sinking, and valuable wildlife habitat is being lost.

An estuary is not only affected by activities within its watershed, but it is also vulnerable to pollutants which enter with the ocean tides. Puget Sound beaches are sometimes the final destination of marine debris from as far away as Japan. Oil spills are a constant threat to estuaries, not only in areas like the Gulf of Mexico, Alaska, and the Persian Gulf, where oil is a major industry, but anywhere there are ships in the water.

Shoreline Development

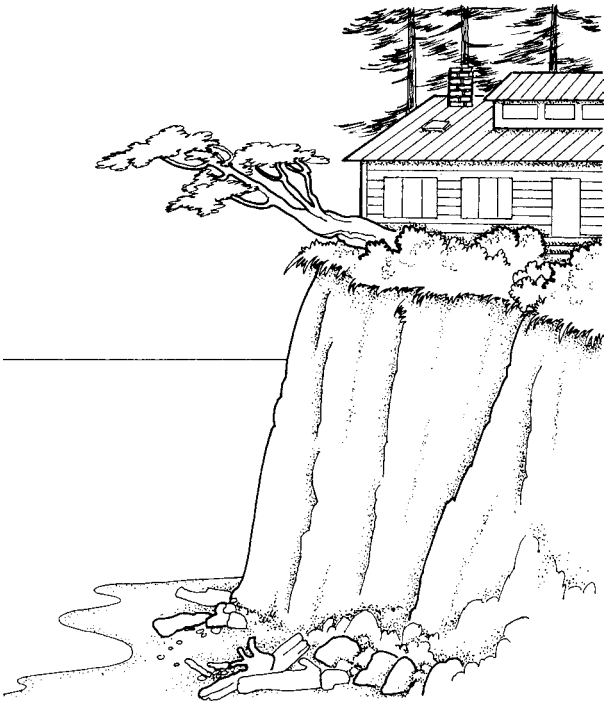
People are attracted to the coast. The population of coastal areas is growing much faster than inland areas, placing intense development pressure on our estuaries. The Puget Sound region is the most heavily populated area in the Pacific Northwest, home to about 3.2 million people. That number is expected to increase to 4.4 million in the next 20 years. As more people arrive, waterfront property will become more and more valuable for housing and industry.

In our society, a house on the shore is very desirable and valuable. A small house on Samish Island, on the north shore of Padilla Bay is worth more than twice as much as a comparable house a few miles inland. Our aesthetic values tell us that the closer we are

to the water, the better. Homes have often been built right at the land's edge, perhaps with a spacious deck suspended over the water.

Improper shoreline development poses problems for the estuary system. Much of the current development in the Puget Sound region is in relatively rural areas without sewage treatment facilities. Private septic systems often fail to function properly, expecially when located near the shore. This can result in bacterial and organic pollution of estuary waters.

Another problem with shoreline development stems from the temporary and changing nature of the coast. Beaches are moving environments, fed by river sediments and the erosion of bluffs. As soon as people build a home or business on the shore, they want to stop this natural change. The most obvious
way to do this is to build a wall between the land and the sea. In highly developed King County, over half of the shoreline is hidden behind some type of bulkhead or erosion control structure.



Many bulkheads and sea walls simply don't work. When they do work, they interrupt the natural movement of sediment along a shore. A single bulkhead often causes more erosion to the properties on either side. A bulkhead protecting a house on a bluff can result in the loss of a nearby beach that depended on the bluff's erosion for its sediment.

In an estuary like Puget Sound, where the shore is often steep, erosion control structures can disturb the narrow intertidal area which is vital habitat for many marine plants and animals. The best answer to the erosion problem is to build back from the shore.

State and local governments regulate shoreline development through minimum setback (how far a structure must be from the shore), zoning (what types of structures are allowed and how dense), and septic codes. The pressures of a growing population and the high value of shoreline property cause homeowners and developers to make maximum use of their property. In spite of current regulations, governments often lack the staffing and resources to adequately protect these sensitive areas.

Introduced Species

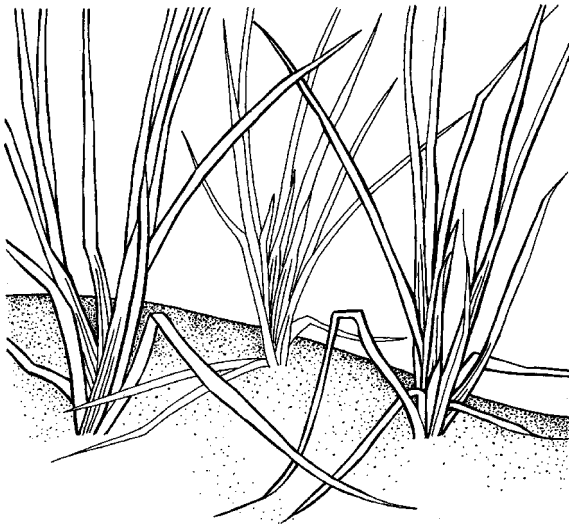
Padilla Bay today is quite different from what it was when the first Europeans arrived. The shape of the bay and the face of the surrounding land have changed dramatically. More subtle changes have occurred in the bay itself with the introduction of new plant and animal species.

An estuary, like all ecosystems, is

characterized by an array of organisms -- organisms which have evolved together into complex, balanced, interacting communities. When a new species is introduced into such a community, it can change the balance and affect the entire system. Sometimes an introduced species will fit into its new home causing little more than a slight shift in population balances. Sometimes, however, non-native species can be devastating.

When an organism is introduced into a new environment, it often has no natural predator and can therefore overcome the native species in the competition for food or space. Most of our serious agricultural pests are introduced species, and have become a problem because there is no natural check on their population.

In Padilla Bay, many of the non-native species arrived with the oyster industry. Though native oysters are edible and were highly regarded by the native people and early settlers, they are too small to be commercially attractive. Oyster growers preferred the large Atlantic oyster or the Pacific oyster from Japan. To cultivate the larger oysters, growers imported "spat," larval oysters ready to settle from their *planktonic* stage. Along with the microscopic oyster spat which was scattered in Puget Sound estuaries, there were seeds of the Japanese eelgrass, *Zostera japonica*. Many species of snails were also introduced from Japan, including *Batillaria attramentaria*, the mud snail which covers Padilla Bay's mudflats, and the oyster drill (*Ocenebra japonica*).



The introduced marsh grass, *Spartina alterniflora*.

A plant which was apparently intentionally introduced in Padilla Bay is cordgrass or *Spartina alterniflora*. On the east coast, *Spartina* is the dominant salt marsh species, and provides important habitat for many animals. In the Pacific Northwest, it can crowd out native species and create a less diverse community. This means that though some organisms may thrive with the *Spartina* there are fewer kinds of organisms. *Spartina* grew in Willapa Bay in small patches for many years until, one year, it started blooming and producing seeds. It is now a serious problem and has covered 2,500 acres of the bay, trapping sediments, eliminating important eelgrass habitat, and threatening valuable oyster and crab habitat.

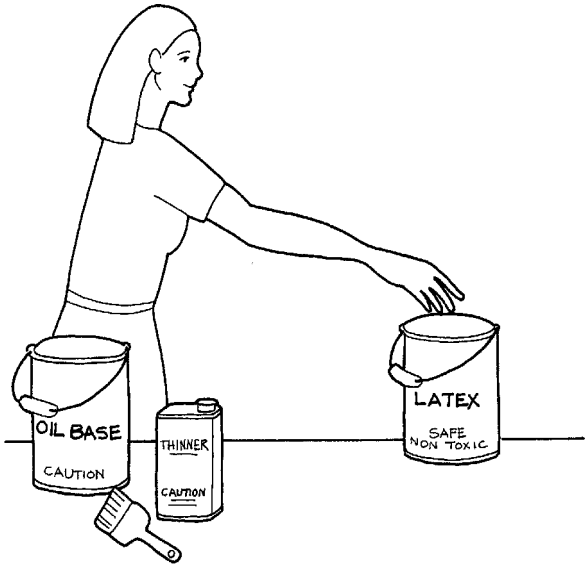
The *Spartina* in Padilla Bay is still limited to several patches, but they are growing larger. Steps to eliminate the *Spartina* in Padilla Bay are being considered now, before it has a chance to flower and become a bigger problem.

What You Can Do

Though the threat to estuaries on a global scale may seem dismal and beyond anyone's control, the picture is not entirely hopeless. While you may not be able to single handedly save the waters of the Persian Gulf, there is a lot you **can** do for your estuary.

In our country, the federal and state governments are responsible for regulations protecting sensitive natural areas like estuaries. These regulations may state exactly how much waste a company can dump into your estuary. They may prevent a port from dredging eelgrass habitat. When making decisions about these regulations, government officials consider public input. They often ask for public comment, though the request may not be extensively publicized. You can find out about public hearings by contacting the relevant government agency or "watchdog" organizations such as local and national environmental groups. (The Audubon Society is one that stays on top of current issues.) Letters from you to the elected officials who determine those regulations **do** make a difference.

Though state and federal agencies regulate our shorelines and water resources, most development projects are actually approved or rejected on a local county or city level -- a level where you, as a high school student and citizen, have the most influence. Often regulations alone are not enough to prevent improper development. When development threatens water resources or wetlands near you, you can contact the government agencies that have information about that area. It might involve the city or county planning department, Washington State Department of Ecology, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, or the U.S. Environmental Protection Agency. Once you know more, then you will be able to voice your opinion on the development in writing or at a scheduled permit hearing. This requires accurate knowledge of the issue, good research skills, and an understanding of all the different view points. It may help to join together with other people who feel the same way you do.



Citizens definitely have influence over development decisions. Edna Breazeale's efforts to prevent major development of Padilla Bay is an example of one person making a difference. But individuals have even more influence over their own actions which affect their estuary.

You, as a high school student, make daily decisions affecting your estuary. The water that goes down the drains in your house may end up in your estuary. What **you** pour down with that water has an effect. When you change the oil in your car or clean out a paint brush with thinner, what you do with the toxic waste makes a difference in your estuary Finding safer alternatives to toxic household chemicals is one thing you can do.

Limiting your water use helps insure that your septic system or sewage treatment facility works properly to clean up the water entering streams, rivers, and bays. Cutting down on car travel by walking, biking, carpooling, or using public transit also cuts down on the toxic runoff from roads, reduces

the need for parking lots and, at the same time, cleans up the air.

When visiting your estuary or beach, you make decisions which affect the organisms there. Handling creatures carefully, filling in the holes you dig, replacing rocks, and walking gently in areas where walking is allowed, all make a difference, especially in heavily used areas like parks.

We are all tempted to blame environmental problems on "them;" big, intangible entities like industry, development, or society. In reality, it is individual people or groups of people that make the decisions which affect places like estuaries. You, your friends, your neighbors, and your family can make informed decisions. You can choose activities that are compatible with the health of natural systems.

Related Activities:

Water Quality Monitoring, Activity 3.

Thinking Globally, Activity 6.

What We Can Do for Estuaries, Activity 7.

Questions

1. List three ways humans have changed estuaries and the human use that it was changed for.

2. Match the city with the river forming its estuary:

London	Duwamish
St. Petersburg	Thames
Seattle	Hudson
San Fransisco	Potomac
New York	Neva
Washington, D.C.	Sacramento & San Joaquin

3. Name three negative effects of dredging.

4. What watershed do you live in? What body of water does it drain into?

5. Name one human activity in your watershed that could have adverse effects on an estuary.

6. Look at the illustration on p. 60 of the house built on a bluff overlooking the water. Why would this be a desirable location for a home? Why would it be undesirable?

7. What problems might develop from building a structure to control erosion of the bluff illustrated on p. 60?

8. How does the introduction of an east coast cordgrass threaten west coast bays?

9. List five actions you could take to help reduce the stresses on an estuary. Of these actions, identify those that you will do and those you will not do. Explain why.